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PB-265 232

Water Reuse in a Paper Reprocessing Plant

Big Chief Roofing Co, Ardmore, Okla

Prepared for

Industrial Environmental Research Lab -Cincinnati, Corvallis, Oreg Food and Wood Products Branch

Oct 76

PB 265 232

EPA-600/2-76-232
October 1976

Environmental Protection Technology Series

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TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA-600/2-76-232		

4. TITLE AND SUBTITLE	5. REPORT DATE
WATER REUSE IN A PAPER REPROCESSING PLANT	October 1976 (Issuing Date)
	6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
Leale E. Streebin*, George W. Reid*, Paul Law*, and Charles Hogan**	

9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
**Big Chief Roofing Company Ardmore, Oklahoma 73401	1BB610 11. CONTRACT/GRANT NO. S-801206

12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
Industrial Environmental Research Laboratory-Cin., OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268	Final Report 14. SPONSORING AGENCY CODE EPA/600/12

15. SUPPLEMENTARY NOTES

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16. ABSTRACT

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The favorable cost/benefit ratio experienced at the plant demonstrated an economic advantage of in-plant control over end-of-pipe treatment. Attaining zero discharge operation has the further benefit of eliminating the problems, cost, and liabilities associated with operation under a discharge permit. Economic benefits observed during zero discharge operation included reduced water supply costs, reduced wastewater treatment costs improved yield, improved drainage and greater dryer section production. The benefits were partially offset by shorter felt lives, increased corrosion control cost, and process modification cost. No degradation of product quality was observed.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Industrial waste treatment, Industrial wastes, Roofing, Materials recovery, Paper mills, Paper industry, Water conservation	Wastewater treatment, Water reuse, Slime control, Paper quality, Physical treatment, Paper reprocessing, Product recovery, By-product recovery, Corrosion control	13B

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
Release unlimited	Unclassified	95
	20. SECURITY CLASS (This page) Unclassified	22. PRICE PC A05 / MF A01

EPA Form 2220-1 (9-73)

*U.S. GOVERNMENT PRINTING OFFICE: 1977-757-056/5495

EPA-600/2-76-232
October 1976

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-CI) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

"Water Reuse in a Paper Reprocessing Plant" is a product of the above efforts. It discusses the feasibility of water reuse in a paper reprocessing plant. The zero discharge technology reduces the overall production costs with no degradation of product quality. The application of such technology is of mutual benefit to both the environment and to industry. For further information please contact the Food and Wood Products Branch of the Industrial Environmental Research Laboratory, Cincinnati.

David G. Stephan
Director
Industrial Environmental Research Laboratory - Cincinnati

ABSTRACT

This project was undertaken to determine the feasibility of water reuse in a paper reprocessing plant with the goal being to "close the loop" or to demonstrate zero discharge technology. Before the project began, Big Chief Roofing Company at Ardmore, Oklahoma, was discharging 7.89 l/sec (125 gpm). Normal operation is now zero discharge with approximately 0.76 l/sec (12 gpm) fresh water make-up replacing evaporative losses. However, weekly clean-ups still result in an effluent of approximately 15.14 M^3 (4000 gallons) a week. Additional clear water storage capacity could eliminate this weekly discharge. Project scope included identifying and solving problems resulting from increased recycle of process water, and determining costs, benefits, and effect on product quality.

The favorable cost/benefit ratio experienced at the plant demonstrated an economic advantage of in-plant control over end-of-pipe treatment. Attaining zero discharge operation has the further benefit of eliminating the problems, cost and liabilities associated with operation under a discharge permit. Economic benefits observed during zero discharge operation included reduced water supply costs, reduced wastewater treatment costs, improved yield, improved drainage and greater dryer section capacity due to increased operating temperatures, and resultant increased production. The benefits were partially offset by shorter felt lives, increased corrosion control cost, and process modification cost. No degradation of product quality was observed.

This report was submitted in fulfillment of Grant Number S-801206 by Big Chief Roofing Company under the (partial) sponsorship of the Environmental Protection Agency. Work was completed as of December 1974.

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ACKNOWLEDGEMENTS

The help and participation of Mr. John Schilling, felt mill superintendent, and other plant personnel at Big Chief Roofing Company are acknowledged with sincere thanks. The work of Mr. William White, formerly project coordinator of Big Chief, is gratefully acknowledged.

The support of the project by the U.S. Environmental Protection Agency and the help of Mr. John Ruppersberger is greatly appreciated.

The assistance of Margaret Johanning in the preparation and editing of the final manuscript is acknowledged with sincere appreciation.

SECTION I

CONCLUSIONS

Based on the findings from this plant scale investigation, the following conclusions were drawn:

1. One hundred percent water reuse is technically and economically feasible in an organic felt mill. To assure 100 percent reuse consistently at Big Chief Roofing, additional clear water storage is required.

2. Product quality has not been adversely affected by water reuse.

3. The operational costs for processing increased slightly. Based on felt life, water use, and pH, slime and foam control, the daily operational costs increased from $73 to $99.

4. The power costs for waste treatment decreased from $34 per day for no water reuse to zero dollars per day for 100 percent water reuse or zero discharge.

5. The total operational costs were essentially the same for all alternatives, i.e., the savings in power costs for waste treatment plus the purchase of water were offset by additional operational costs.

6. Foam and slime control were not significantly affected by water reuse.

7. Scale was not a major problem at Big Chief. The only significant operating problem resulting from scale and other deposits was blinding of the Zurn micromatic screen which reduced its throughput.

8. Maintenance problems have not increased significantly during the period of water reuse.

9. When water reuse is practiced, the process water chemical concentration increases from 2 to 6 times the concentrations under conventional operating conditions.

10. Corrosion of plant equipment resulting from water reuse can be adequately controlled by maintaining the pH above 6.0.

11. The pickup felt life decreased with an increase in water reuse. Average felt life was 75 days during no water reuse and 50 days during 100 percent water reuse.

12. Tentative results indicate slime deposits and the resulting slime holes in the product can be effectively controlled by the addition of 3 mg/l of a mixture of quaternary ammonium compounds to the system.

13. Kerosene satisfactorily and economically controls the foam.

14. The hydrasieve satisfactorily removes the coarse suspended solids from the system but does not prevent plugging of the showers for cleaning the pickup felt.

15. The micromatic screen has not functioned satisfactorily since its installation. The removal efficiencies were much lower than expected and numerous mechanical failures prevented its use during a significant portion of the study. When it was operating satisfactorily, however, it did prevent plugging of the shower for cleaning the pickup felt.

16. Should the clays and other fillers from the waste paper concentrate and reduce the porosity in the product, the ratio of wood flour to waste paper could be changed to maintain the required porosity.

SECTION II

RECOMMENDATIONS

Based on the results from this study, the following changes and/or additions are recommended:

1. Develop methods for disposing of the sludge from the bottom of the filtered water storage tanks. Possible methods include: 1) maintaining the sludge in suspension, thereby allowing it to be deposited on the felt mat, 2) pumping the sludge from the bottom of the tanks through an atomized spray nozzel onto the felt mat, 3) concentrate the sludge and place in a landfill or spread on land.

2. Develop methods for removing the dissolved solids and a higher percentage of suspended solids which would allow 100 percent water reuse in a paper reprocessing plant manufacturing higher quality papers.

3. Install automatic pH controls and continuous chemical feed systems.

4. Develop a monitoring and information system for production personnel which would include liquid level alarms, conductivity, and pH sensors which would indicate deterioration of water quality.

5. Insure adequate surge and storage capacities for filtered white water. At Big Chief Roofing, this required a minimum of 113.56 M^3 (30,000 gallons) during the period when the hydrapulper was used and 227.12 M^3 (60,000 gallons) when the paper beater was used.

6. Select a microscreen for removing solids from the white water to insure uninterrupted operation of the showers.

7. Select a microscreen with a capacity, at expected solids loading, equal to the peak flow into the white water pit. At Big Chief the peak flow is three times the average flow to the filtered water storage tank.

SECTION III

INTRODUCTION

PROJECT OBJECTIVES

The objectives of this project were to decrease or possibly eliminate liquid waste from paper reprocessing industries. In the past, since the cost of fiber from used paper was inexpensive, high waste treatment efficiencies were not required or enforced, and in many cases water was plentiful and relatively inexpensive. For these reasons, the recovery of fiber and the conservation or reuse of water was not considered justifiable. With the advent of PL 92-500 (1), state and federal regulatory agencies require higher effluent qualities resulting in higher treatment efficiencies. Therefore, industries are investigating least cost methods of pollution control. These methods include water reuse, and product and by-product recovery.

The specific objectives of this study were to:

1. Determine the feasibility of total water reuse, thereby eliminating any waste discharge and the attendant waste disposal problems.

2. Determine effects of water reuse on product quality.

3. Predict the increase in operational costs due to increased corrosion rates, scale formation, slime growths and solids deposits.

4. Determine savings from decreased waste treatment costs, fiber losses, and water use.

5. Conduct a cost-effectiveness analysis of alternative combinations of water reuse and by-product recovery versus waste treatment.

NEED FOR PROJECT

This study was directed toward control of water pollution from paper reprocessing industries. The potential for these industries is prac-

tically unlimited since paper is the largest individual component of municipal solid wastes. It constitutes more than 45 percent of the total waste volume generated each year. If segregated and satisfactorily processed for reuse, the waste paper would provide approximately 25 percent of the raw material for the paper industry (2).

At the end of World War II, approximately 35 percent of the wood fiber products were recycled in the United States but since that time the percentage of paper stock utilized as secondary fibers has continued to decrease. The reason for this decrease is that certain mills can produce virgin pulp ready for a paper machine at costs less than that for recycled fiber (2). Although the virgin material may presently be cheaper, if the cost of solid waste disposal, and the social costs of resource reductions and solid wastes are considered, it can be anticipated that paper recycling will be favored in the future. It is, therefore, necessary to determine the least cost method of pollution control for the industries. This method may be total reuse or zero discharge.

There is a need to determine the feasibility of water reuse in a paper reprocessing plant with the goal being to "close the loop" reducing wastewater discharged and water requirements. As mentioned in the report, "Cost of Clean Water", (3) data are not available to compare the expenditures for in-plant modifications with the cost savings in wastewater treatment, a cost-effectiveness analysis. This study defines the problems resulting from recycling of the process waters, determines the magnitude of these problems, and develops methods of control thereby increasing the reuse factor with the ultimate goal being complete reuse, i.e., zero liquid waste discharge.

There are a great number of paper mills nationwide that use reprocessed fiber for making wall board, container board, boxboard, building paper, building board, composition shingles, etc. In Oklahoma, there are four

mills using reprocessed fiber. One produces paper for dry wall, two produce felt for composition shingles and also further process the felt into shingles and one produces both felt for shingles and paper for dry wall. This study was conducted on a felt mill. There are more than 60 of these plants nationwide. Three of these are within 322 km (200 miles) of Ardmore, Oklahoma, the home of Big Chief Roofing where the study was conducted. Two of these felt mills plus both of the Oklahoma plants that produce paper for dry wall are experiencing problems with their waste treatment systems and will have to expand them or convert their plants and practice more water reuse. The other plant producing composition shingles essentially has a "closed loop" but is experiencing high operational and maintenance costs.

SECTION IV

LITERATURE SURVEY

INTRODUCTION

The pulp and paper industry, like most industries, is currently faced with the dual problem of diminishing sources of water and more stringent water quality standards for its effluent. The pulp and paper industry is particularly vulnerable to increasingly stringent water controls because of high water usage. The paper industry is the third largest user of water. Liquid wastes resulting from pulp and paper mills have a potential for polluting surface waterways on the basis of their high volume, BOD and suspended solids. Regulatory agencies have set pound per ton production limits on BOD and suspended solids which may be met by reducing the effluent concentration, reducing the effluent volume or a combination of both.

The Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) declared as a national goal that the discharge of pollutants into navigable waters should be eliminated by 1985. This is commonly referred to as "zero pollutant discharge". In attaining this goal, an attempt has been made to spread the economic impact over two five-year interim goals. No later than July 1, 1977, most industrial sources must achieve effluent limitations which require application of "the best practicable control technology currently available". No later than July 1, 1983, effluent limitation must be achieved by most industrial sources which require application of "the best available technology economically achievable".

In the pulp and paper industry, personnel who have broad technical knowledge in the industry generally concur that an existing mill cannot economically achieve zero discharge of wastewater unless some peculiar set of circumstances exists. They also feel that new mill complexes may be able to achieve zero discharge if certain processes in the

developmental stages are proven in practice in combination with other systems and if an appropriate mix of industries or systems can be arranged at a single location (4).

To approach the 1985 goal will require a combination of reductions in wastewater generation, maximization of wastewater reuse, and the development and application of unique new treatment techniques. Major factors which determine the feasibility of water reuse are the effect of reuse on product quality, the frequency of accidental discharges of wastewaters, and the ability to dispose of liquid wastes adequately without polluting ground water or the air. Wastewater streams have been reused in the pulp industry for many years in order to reduce fiber, heat, and chemical losses as well as to reduce raw water demands. Haynes (5) reported that in the Southern Kraft Industry, the reuse of process waters was, on the average, 240 percent of the intake.

The technology required to achieve the 1985 goal at some mills is available as demonstrated by a system developed for the Charmin Paper Company by C.A. Barton, et al (6), and Celotex Company by A.H. Phillip (7). Specific processes which have been utilized by some paper industries to treat their wastewaters include microstraining for more efficient fiber and solids removal (8), reverse osmosis (9 & 10), and the use of special strains of microorganisms, e.g., soil microorganisms for microbiological breakdown of fibers, cellulose and lignin (11).

A discussion of the status and needs for the paper industry's water protection technology is given by Gellman and Blosser (12). It covers the processes used for effluent clarification, sludge dewatering and disposal, removal of oxygen-demanding, non-settleable materials and improving aesthetic effects of effluent waters, i.e., odor, foam, color and turbidity.

Water reuse or recirculation is becoming more attractive in many areas of the country because of the effective manner in which it deals not only with water pollution, but with the limited water supply. Numerous

industries, e.g., steel, pulp and paper, sugar beets, are already practicing water reuse or recycling in their plants.

J. Eller, et al (13), distinguishes reuse as the utilization of water that has been used previously for another purpose and recycling as the use of the same water one or more times for the same purpose. An example of water reuse is the direct use of municipal wastewaters as cooling waters by steel plants. Successive use of waters, however, needs to meet certain water quality standards and oftentimes these waters have to be subjected to some form of treatment. A broad spectrum of quality criteria exists for industrial water supplies because of the highly variable nature of industrial water use. Some of these criteria are given in a paper by K. D. Lindstedt, et al (14).

In the case of recycling, relatively large volumes of water are made available for reuse while the raw water inflow is relatively small. Intake is limited by the amount lost by evaporation, consumption or blowdown. If blowdown is not desirable, dissolved solids build up may be controlled by the inclusion of a treatment step into the recycle system (6). Several methods of removal of excessive organic or inorganic materials in the recirculating water are available.

J. E. Eller, et al (13), offers an economic comparison of once-through and recycle systems along with the following observations:

1. The feasibility of recycling with respect to cost depends upon the savings appreciated by handling a smaller volume of water as compared to the cost of treating the effluent for recycle.

2. Recycling systems are best when contaminant additions are either low or easily removed and quality requirements are not stringent; e.g., cooling operations.

3. Recycle systems often allow for product recovery not possible in once-through system.

4. Recycle systems offer more attractions as final effluent requirements become more stringent.

WATER RECYCLING AND RENOVATION

The sheet formation and drying operations have received the greatest attention in water reuse programs since a large volume of high quality water is utilized in these processes. In these operations, recycling of white water is mandatory because of low fiber consistency of the furnish which flows to the headbox of the paper machine. The web of pulp which is formed on a Fourdrinier, cylinder, or other drainage wire must drain sufficiently before it is lifted from the wire and transferred to a pressing and drying section. Since a large volume of water drains through this wire, a high flow rate is necessary. This flow rate is maintained if the fiber and fragments which are deposited in the forming device are removed. This is accomplished by washing with high pressure showers that use filtered white water.

Albert Thomas (15) demonstrated a "closed loop" white water system for manufacture of tissue and paper towels. In his system, there were two main sources of water for reuse: 1) filtered water from three save-alls, and 2) the remaining clean white water. The higher quality water was used in the wire showers (except breast roll shower) on all machines. It was also used for sealing water in the Nash vacuum pumps. The poorer quality water was used for stock dilution at the save-all, machine repulper, and machine chest consistency regulator. By closing up the white water system, the effluent from the mill was reduced by about 4921 M^3/day (1.3 mgd) and the fiber loss reduced from 2.3 percent to less than 1.0 percent.

Lyman Aldrich and Raymond Janes (16) studied a system producing high opacity offset paper. On three continuous 3-5 day runs using a 76.2 cm (30 in.) wide Fourdrinier paper machine, no operational problems were encountered when 97 percent water reuse was practiced. Closing the water system from 72 percent to 97 percent resulted in the following benefits: 1) savings of 18 percent of fiber while maintaining opacity and ash content, 2) savings of 50 percent alum and 20 percent resin while maintaining sizing, and 3) a 50 percent reduction in total BOD in the effluent.

Negligible differences (less than 10 percent decrease) were found in paper strength properties, suspended solids, felt filling or pressing efficiency, dirt in paper, and printability.

Water from the press section is usually the last source for which recycling is attempted, but some mills are straining this water to remove felt hair and are recycling it along with other white water. Usually felt hair contamination varied with the running time of the felts. Less than 20 percent of the felt hairs were of a size considered to be troublesome in printing grades. Tests with several types of screens indicated good felt hair removals and filler recovery. With a 325 mesh stainless medium, 80 percent removal of the felt hair was achieved. Removal of wool felt hair was 97 percent, removal of the smaller, smoother synthetics was 55 percent. Filler recovery was 90 percent (17).

The vacuum pump systems, if operated with the proper amount of seal water, conserve both water and power. An excess amount of seal water causes excessive water use, requires more power, and reduces pump capacity. This problem can be eliminated at each pump by using pressure reducing valves and properly sized orifices. This combination provides just the correct amount of sealing water necessary for good operation. A seal water shutoff valve should be interlocked with the pump's prime mover to prevent flow on shutdown (18). Reuse of vacuum pump seal water is accomplished either by treating the pump water system as one link in a series with one or more other water systems, or as a separate closed cycle (19). The former involves one of the following methods:

1. Feeding the pumps with fresh water and discharging to another system.

2. Feeding the pumps with reused water and sewering the discharge.

3. Feeding the pumps with reused water and discharging to another system.

The first and second methods reduce both fresh water demand and effluent discharge by a volume equivalent to the vacuum pump seal water flow. The

third method reduces fresh water demand and effluent by as much as twice the vacuum pump flow.

A closed system of seal water for vacuum pumps can result in an increase in temperature with a corresponding decrease in vacuum. The temperature and vacuum can be controlled by installing cooling towers or by adding fresh water.

The Venta Nip Presses, which have become so popular for water removal in press sections, require shower water. Therefore, the consumption of fresh water on the paper machine increases when these presses are used. This problem can be solved by recycling the vacuum seal water or by using white water as the shower water. This white water was passed through a 40 mesh screen to prevent plugging of the showers. Showers which have been the most successful in white water service are the self-cleaning types such as the Bird-Aquapurge or the Broughton (5).

A lime-magnesium precipitation system is used to recondition the white water as make up for a tissue operation of Kimberly-Clark at Fullerton, California (20). This has resulted in lowering make up water requirements to 23.32 M^3/metric ton (6500 gal/ton) compared with 85.88 M^3/metric ton (25,000 gal/ton) at another modern installation where water reuse is not practiced. Pressure filtration methods have also been used to improve the quality of the white water. A system was developed for recycling white water by W.S. Davis and others at Weyerhaeuser Company, Miquon, Pennsylvania (17). Process effluent was collected from individual paper machines and then pumped to a surge tank. From here it flowed to the primary clarifier. After chemical treatment and coagulation, the white water was filtered through a special sand and gravel filter to remove the last traces of turbidity. Problems encountered at the beginning of the program included plugging of the sand filter, slime build up in the holding tank and filtered water lines, and the residual color remaining in the filtrate. Apparent color and slime problems were solved by adding enzymes to the clarifier at a level of six parts per million. The enzymes suppressed the dispersing power of the starch and degraded

the starch molecules enhancing settling of the clay and titanium dioxide particles (as well as the fiber fines and the color bodies attached to them). Particles that were not removed by the clarifier were easily removed by the filters. Removal of apparent color and suspended solids from white water has permitted the use of make up water consisting of 15 percent reconditioned white water.

According to a survey by the Water Division of TAPPI (5), most of the water recycling program emphasis is within the paper processing area. One of the reasons is that a number of the nonintegrated paper mills are quite old and were constructed when there was little thought given to the water required in the process. The significant factors promoting recycling of water were water supply problems and the need for fiber recovery systems. The recycling schemes reported were all quite simple. Most of the installed hardware was for the purpose of recovering fiber, whereas the recovery of water for recycling was incidental.

A study reported by Leo J. Eimmerman (19) has outlined the steps of a water recycling program. The first phase of the program consisted of preparing a detailed flow diagram of all operations. The second step was to measure the water flow quantities and to verify them by a water balance. Once the flow diagram and balance were complete, a detailed study on each system and subsystem determined if they could be modified or operated in a manner to reduce water consumption or to reuse water. Some potential water conservation and recycle methods were cited in the report. In the paper machine area, many potential savings were possible. Fresh water showers should be kept to an absolute minimum, but where used, flows should be as low as practical. If possible, the showers on existing machines should be converted to use clarified white water. Older showers should be periodically rechecked and nozzles changed if found to be worn. Main sheet knock off showers should be controlled to operate on break only. Pump pressures should be monitored and controlled to prevent high flows.

Well designed save-all systems with proper controls along with adequately trained personnel will increase water savings considerably. If they are not operated properly, the resulting poorly clarified white water will cause shower plugging, a loss of production, and shortening of felt life. A save-all should be operated on a steady flow basis for the best clarity and all excess cloudy water recirculated with only the clearest water released from the system (19).

A promising approach to water reuse has been proposed for a bleached Kraft operation (21). This approach proposes to alter processing to facilitate water recycling. This was to be accomplished by:

1. Washing the pulp in a completely countercurrent fashion, from the final bleach stage to the brown stock washers.

2. Using cleaned, evaporated condensate to wash the bleached pulp.

3. Using a mixture of chlorine and chlorine dioxide in the chlorination (first) stage of bleaching.

4. Recovering the spent bleaching chemicals, namely sodium chloride by evaporating white liquor.

5. Using part of the pure crystalline sodium chloride to make sodium chlorate; using additional sodium chloride along with sodium chlorate and sulfuric acid to make all the chlorine dioxide and chlorine required for bleaching, and to make all the sodium sulfate required for make-up of pulping chemicals.

The effluent-free Kraft mill can be achieved with existing technology and process equipment not radically different from that now used in Kraft mills. However, removal of heat from the mill may be a problem and may even require an evaporative air cooler. It would be advantageous to generate as much electrical power from the excess heat as possible (22).

There are several tertiary treatment schemes proposed to upgrade the mill discharge and make it suitable for water reuse. A process to produce a clear, colorless effluent from a bleached Kraft mill was devel-

oped by Fuller and reported by Haynes (5). According to Haynes, "The combination of an activated sludge process and chemical precipitation with alum reduced biochemical oxygen demand (BOD) to less than one part per million and the color to five chloroplatinate units". This, Haynes stated, was a remarkable achievement considering the high color and BOD from a Kraft mill discharge. The problem encountered in this process was the high dissolved solids content which was approximately 520 mg/l. This process could be utilized to augment mill supply but complete recycling would result in a higher dissolved solids content than could be tolerated.

Reverse osmosis has been applied to a water reuse program (23). Reverse osmosis is a unit operation in which clarified water is separated from the remaining wastes for process reuse, and the organics are concentrated for processing by more conventional techniques. Significant problems have resulted from use of this system. It has been impossible to obtain a high concentration of dissolved solids in the concentrate from the reverse osmosis system. The process is capable of concentrating a stream containing one percent to ten percent dissolved solids and recovering 90 percent of the process water for reuse. This leaves too much residual volume for disposition without further concentration by evaporation. Other problems encountered include an extremely high pressure drop across the membrane, over 42.18 kg/cm^2 (600 psig), and low flux rates, 81.5- to 407.5 $l/day/M^2$ (2-10 $gal/day/ft^2$). Although the reverse osmosis process does not represent a complete solution for water recycling in the pulp and paper mill, it does have a place. This process has the potential of removing not only color and BOD but also dissolved solids, both organic and inorganic. At Green Bay Packaging, Inc., Green Bay, Wisconsin, a method of recycling weak waste has been developed and incorporated that results in volume reduction and pollutant concentration in the waste stream.

Rapson and Reeve (22) forecast "substantial savings" in both capital and operating costs for an effluent-free bleached Kraft pulp mill. The net capital savings (compared with complex water treatment facilities) is $6 million for a 907.2 metric ton/day (1000 ton/day) mill. Net operating cost savings is $9.65/metric ton ($8.75/ton) of bleached pulp.

The significant capital and operating savings are supplemental to the main advantages of elimination of aqueous effluents from the bleach Kraft pulp mill, namely: 1) prevention of aqueous effluent with a resulting increase in pulp yield, 2) elimination of the sodium chloride now being introduced into the receiving streams, 3) elimination of the problem of color in effluents which is usually not removed and is often enhanced by secondary treatment, 4) elimination of the toxicity of pulp mill effluents, much of which remains after secondary treatment, and 5) elimination of dissolved organic matter which consumes oxygen in the receiving streams. Another problem avoided is that of introduction of nutrients (nitrogen and phosphorus compounds) used in secondary water treatment. These nutrients are subsequently introduced into the receiving stream and their elimination will help prevent the growth of unwanted algae and other microorganisms (22).

Up to this point the methods and benefits of water recycling have been discussed. There are also problems that arise as a result of water reuse.

PROBLEMS IN WATER RECYCLING

Problems resulting from water recycling can be categorized as: 1) corrosion, 2) scale, 3) biological slimes, 4) foam and 5) decreased product quality and production rates. As the percentage of water reuse increases, the related problems will become more complex and interrelated. Naturally, the problems mentioned may not all be present in the mill at any one time, nor may they manifest themselves to a point where they significantly affect operations. Nevertheless, they should be considered as endemic to systems that have a high water reuse rate. These problems are interrelated and thus, will occur in combinations.

Corrosion

Corrosion is one of the major problems accompanying a tight water reuse or recycle system resulting in reduced equipment life. The amount of

corrosion that may be tolerated in an industrial plant depends on the equipment involved. In a thick-walled pipe carrying water, a large amount of attack can proceed before holes develop. On the other hand, on high speed equipment such as pumps or a paper refiner, a small amount of corrosion in a localized area may result in complete failure.

Corrosion due to water recycling can assume many different forms and can be present in most areas of the mill: 1) the steam generating facility, 2) stock preparation areas, 3) the paper forming area, 4) the dryers and 5) in the water treatment system. The different forms of corrosion associated with water recycling include electrolytic corrosion, corrosion associated with protective films, and bacterial corrosion.

The reaction of metals with aqueous environments is called electrolytic corrosion. The reactions involved in electrolytic corrosion are electrochemical in nature and are given by T. P. Hoar (24), C. F. Cheng (25), M. Pourbaix (26), and others (27 & 28) to explain the corrosion process. In electolytic corrosion, metal leaves the metallic state by anodic dissolution to aqueous cations in solution or by anodic conversion to a solid compound. These reactions are accompanied by an equivalent cathodic reduction of some constituent in the aqueous electrolyte. The anodic and cathodic reactions depend on the type of metal involved and the nature of its aqueous environment. Iron and alloys based on iron can be corroded in both aerated solutions and deaerated acid solution.

In aerated natural waters, oxygen reduction is the predominant reaction at the cathode. The products formed are hydrated ferric oxides and magnetite. None of these products of attack provide any marked restricting influence on the electrochemical process. Their adhesion to the surface and their protective action are much weaker than that provided by calcium carbonate; thus, the corrosion of iron in soft waters does not decrease appreciably with time (25).

In a solution with a pH value of about four where the concentrations of dissolved oxygen and hydrogen ions are comparable, the hydrogen evolution type of attack becomes increasingly important. This evolution of hydrogen occasionally gives rise to some concern in the corrosion of iron and steel in closed systems where the presence of a flammable gas may be demonstrated. This is due to the ability of iron to liberate hydrogen from water. In closed systems the small amount of oxygen present initially in the water is soon consumed and subsequently a slow cathodic evolution of hydrogen takes place. Simultaneously, a film of magnetite is formed on the metal surface which eventually stifles further reaction (25). Even in the absence of air, corrosion of iron can take place in waters if sulfate reducing bacteria are active. These bacteria are present in most waters and in systems where the sulfate concentration is adequate. They will proliferate in regions where the oxygen concentration is sufficiently low. The bacteria are able to use the cathodic hydrogen which would otherwise slow down or stop the corrosion process (25 & 29).

In any given circumstance more than one of the above reactions may participate in the overall cathodic process and the predominant reaction may vary with time. In acid solutions reduction of heavy metal ions and hydrogen ions can occur, while in only slightly acidic or alkaline solutions a certain amount of hydrogen is evolved even when oxygen is present. In a closed vessel or in one where oxygen is limiting, corrosion can proceed by oxygen reduction until all the oxygen has been removed; then sulfate reducing bacteria can take over (30).

Corrosion can be affected by the corrosion product itself due primarily to electrochemical polarization during the formation and breakdown of these protective films (25). The nature and properties of the protective films that form on some metals or alloys are very important from the standpoint of resistance to corrosion (31). The ability of these films to protect the metal depends on the speed with which they form when originally exposed to the environment, their resistance to wear, and the rate of re-formation when destroyed or damaged.

Stainless steels depend heavily on a protective film for their resistance to corrosion. Variations in the amount of attack on steel by water with varying pH but constant velocity are apparently due to the nature and composition of the surface scales formed. Carbon steel exposed to distilled water at 50°C (122°F) showed little attack at pH values of 6 and 10, and high rates at a pH of about 7 to 9 and below 6. The scale on the species exhibiting high rates of deterioration were granular in nature and consisted of magnetite. Below a pH of 5, the corrosion product film was increasingly more soluble as the pH was reduced. In regions of low attack, the corrosion products were ferrous and ferric hydroxides which are more protective probably because they hinder the transfer of oxygen and ions (31).

Tests on copper and brass in sodium chloride solutions with or without oxygen showed that copper was attacked more often than brass in the oxygen saturated solution. The copper was covered with a black and yellow-brown film of cupric chloride, while the brass was covered with a more protective, dark gray cupric oxide film (31).

Investigations dealing with corrosion mechanisms often deal with properties of the corrosion products formed (32). Several forms of corrosion can be the result of reactions between metal surfaces and the corrosion medium. Some of these are listed below.

Tuberculation--Tuberculation corrosion is formed by iron consuming or iron depositing bacteria such as Crenothrix and sulfate reducing bacteria such as Sporovibrio desulfuricans.

Uniform attack--This is the most common form of corrosion. It is normally characterized by a chemical or electrochemical reaction which proceeds uniformly over the entire exposed surface. The metal becomes thinner and eventually fails.

Galvanic or two-metal corrosion--This condition occurs when two dissimilar metals are in contact with each other (or

otherwise electrically connected) and exposed to a conductive solution. A potential is set up and a current flows. Corrosion on the less corrosion resistant metal is increased and attack on the more resistant material decreased as compared to their behavior when not in contact. The most familiar example is galvanized steel pipe which is pipe coated by dipping in or electroplating with zinc.

Concentration cell corrosion--This can also form because of differences in the environment. The two most common are metal ion cells and oxygen cells.

1. Metal ion cells--a metal tends to corrode at a slower rate as the concentration of its ions in solution increases. Metal in contact with a more dilute solution will become anodic and metal in contact with a more concentrated solution will be cathodic.

2. Oxygen cells--oxygen concentration cells develop where there are areas low in oxygen and others high in oxygen content. Concentration cells may be caused by differences in velocity of the solution. They are associated with essentially stagnant conditions which may be caused by holes, gasket surfaces, lap joints, surface deposits and crevices.

Graphitization--Gray cast iron sometimes shows the effects of selective leaching particularly in relatively mild corrosive environments. The cast iron appears to become graphitized in that the surface layer has the appearance of graphite. What happens in graphitization is a selective leaching of the iron or steel matrix and an interlocking graphite network is left behind. The carbon is cathodic to iron and an excellent galvanic cell exists. White cast iron has essentially no free carbon, hence it is not subject to graphitization.

Erosion-corrosion--The acceleration of the rate of deterioration of a metal because of movement between a corrosive

fluid and the metal surface is called erosion-corrosion. Generally this movement is quite rapid, and mechanical or abrasion effects are often involved. Metal is removed from the surface as ions or it forms corrosion products which are swept from its surface. This type of corrosion is, therefore, enhanced by an increase in velocity.

In order to make any evaluation of the probable corrosive action of a water in a paper reprocessing plant, it is essential to have adequate knowledge of the physical and chemical properties of water. Factors that must be considered are: temperature, pH, flow velocity, dissolved constituents in the water, how these vary during processing, and possible ways in which the water quality can be economically improved in order to reduce corrosion. Therefore, the possible direct or secondary influence of increased concentrations of pollutants and the presence of various microorganisms due to reuse must be considered.

Dissolved oxygen (DO)--For a water of a given pH, an increase in the dissolved oxygen level results in a near linear increase in the corrosion rate up to a maximum (30). For distilled water, the critical level is approximately 8 mg/l at 25°C (77°F). This is increased as the temperature is raised or increased by the presence of dissolved salts. It is decreased by an increase in water velocity and pH being only 4 mg/l at pH 10. The ultimate decrease in corrosion rate at higher oxygen levels results from the formation of passive films on the metal surface. The effects of dissolved oxygen is related to the rate of formation, nature and stability of the protective film.

Dissolved ions--Substances which give rise to hydrogen ions in solution are reported to increase the corrosiveness of the medium. These are organic acids which originate from wood and wood pulp (33 & 34).

Some anions like chromate, phosphates, silicates, and borates decrease corrosion rates and are known as inhibitors, while others like chlorides and sulfates are known to enhance corrosion and are classified as aggressive ions. These anions have been shown to increase the corrosivity of iron, aluminum, chromium and iron-chromium alloys, while not affecting tantalum, titanium, zirconium, molybdenum or tungsten. Butler and Stroud (35) found that the rate of corrosion of mild steel varied directly with chloride concentration. Other investigators (36 & 37) evaluated the effect of chloride and other ions on steel and reported that chloride and sulfate are the ions most detrimental to steel although the presence of other salts, e.g., of bicarbonate also exert an accelerating effect on corrosion rate.

Velocity--The effect of velocity on aqueous corrosion is complex. An increase in water velocity usually results in enhanced corrosion rates through depolarization of the cathodic reaction by ensuring a more plentiful supply of oxygen. It may also sweep away partially protective corrosion products. It is possible, however, for increased flow rates to prevent corrosion by reducing the number of stagnant areas and so prevent differential aeration cells from becoming established. At very high flow rates, corrosion varies with pH and the high corrosion rates are associated with the formation of a less protective magnetite film (25). Critical velocities vary for different metals.

Temperature--The effect of temperature varies with the nature of the system. The corrosion rate approximately doubles for every $30^{\circ}C$ ($86^{\circ}F$) rise in temperature until all the oxygen is consumed, then the rate falls. In an open system, the corrosion rate increases with temperature rise until the decrease in solubility of oxygen outweighs the accelerating effect of temperature.

With use the composition of water often changes either by evaporation, the extraction of steam in steam generating equipment, or in the addition of pollutants during use as process waters. This will result in an increase in dissolved solids, and unless water is regularly bled off, the concentration may become very large. Furthermore, the content of aggressive salts such as chlorides and sulfates increases continuously owing to their high solubility while, at the same time, scale forming salts, having a low solubility, are precipitated. This results in an increase in aggressive ion concentration and a decrease in the concentration of potentially restricting ions. The amount of water reuse in certain circumstances may be dictated by the magnitude of the increase in corrosion and the difficulty in corrosion control.

Several methods to control corrosion rates are available. These methods include: selection of corrosion resistant materials; cathodic protection; insulation between bimetallic surfaces; protective coatings; water treatment which includes ion removal, pH control and, the addition of inhibitors and restrainers. Inhibitors or restrainers include: calcium bicarbonate, chromates and dichromates, nitrites, polyphosphates, silicates, sodium benzoate and organic inhibitors.

Material selection--The basic problem in the prevention of corrosion is the correct selection of a material at the design stage. The success of this aspect of corrosion control will depend upon: knowing in advance the reuse engineering and corrosive conditions to which an item will be exposed; using a special material must be cost equivalent to making an item of the cheapest material and replacing it on a regularly planned basis; and availability of all the material involved in specifications (38, 39 & 40).

Cathodic protection--This consists of making a metallic structure in its entirety the cathode of a purposely

designed electrochemical cell which protects it from corrosion (31). Sacrificial anodes like magnesium (41) and zinc (27) have been initially used in the protection of steel. Recent reviews of the present state of development of cathodic protection techniques both in the area of sacrificial anodes and impressed current protection systems are offered by J. H. Morgan (42) and J. B. Cotton and others (43, 44, 45 & 46).

Coatings--The materials used for protective coatings may be organic or inorganic. M. Clarke (47) and others (39 & 48) review the more common metal coatings and their methods of application. An extensive evaluation of the properties and resistances of zinc filled inorganic coatings is made by NACE, Technical Unit Committee, headed by M. W. Belue, Jr. (49).

Water treatment--Corrosion cells need electrolytes, the most common being water. Thus, it has been necessary to treat waters involved to reduce their ability to trigger and support corrosion cells. Water treatment methods may be divided into mechanical and chemical. The most popular mechanical technique is the use of deaerators to remove dissolved oxygen. This is usually done under an inert atmosphere. Chemical treatment usually involves the controlled addition of a chemical to alter the corrosive quality of the water which may include:

1. Base exchange or ion exchange--ion exchange resins are used to remove some undesirable ions in the water.

2. pH control--the addition of chemicals to adjust pH can serve more than one purpose. They may bring the pH to acceptable levels, precipitate metallic salts from solution or keep certain salts in solution, whichever condition is required.

3. Inhibitors--an inhibitor is a chemical added to the water to inhibit specific corrosion reactions. Kennedy (50) reported on organic inhibitors for aqueous solution. These inhibitors were relatively non-toxic, film-forming amines which can be absorbed readily on to the metal surface. The resulting organic film then acts as a barrier. These inhibitors were particularly effective in reducing the corrosion brought about by hydrogen sulfide, hydrogen chloride and carbon dioxide. The inhibitors used for iron and steel are organic and inorganic substances whose actions have also been studied by such investigators as Cartledge (51), Hackerman (52 & 53) and others (54, 55, 56 & 57).

Besides preventing local attack or general corrosion, inhibitors and restrainers serve a number of other desirable functions such as avoiding the blockage of pipes and screens by corrosion products, keeping the waters "clean" for biological or aesthetic reasons and maintaining optimum conditions for heat transfer. In a paper reprocessing plant, the prevention of blockages may be more important than the reduction in corrosion since most of the process water eventually passes through the screen on the cylinder of the paper machine.

Scale

The reuse of process water is frequently limited by the formation of scale or similar encrustations in various parts of the recirculating water system. These deposits can plug filters, screens, wires and forming fabrics. They can block or restrict the flow of stock or water through pumps and pipelines and can build up on the paper machine to the point of causing damage to machine clothing and parts as well as reducing the quality of the paper produced.

Scale is a deposit that results from the crystallization, precipitation or coagulation of nonresinous substances. The most common chemical constituent of such deposits are calcium carbonate and calcium sulfate,

although other cations, like iron and manganese could also be deposited as their oxides.

Some of the operational difficulties caused by scale deposits are: 1) obstruction of fluid flow, 2) impedance of heat transfer, 3) wear of metal parts and, 4) localization of corrosion attack (58). Corrosion and scaling often occur hand in hand. When fouling or failure develops, the cause is often traced to a combination of scale and corrosion product deposits. This was found to be the case in a stainless steel digester by Scott (39). Scale deposits cause contact and crevice corrosion and thereby start surface deterioration. Localized attack may occur from an oxygen concentration cell under the scale. Scale also has been found to increase pitting and stress corrosion cracking. This indicates that prevention of scale would eliminate a good deal of corrosion.

The problem of evaluating and solving corrosion and fouling of water systems can be complicated by a continually changing environment, like fluctuations in pH, temperature, velocity, hardness, chloride ion concentration, dissolved oxygen, oxidizable organic material and others. This was found by McAllister et al (59), in their study of scaling and corrosion of condenser tubes exposed to river water. Other important considerations in this study were the addition, at regular intervals, of chlorine for control of biological growth and also addition of caustic for corrosion control. Some of the findings of interest in circulating and recirculating waters are the following:

1. The rate of fouling is not a function of velocity but of chloride ion concentration and hardness.

2. The addition of enough caustic to change the pH from 6.8 - 7.1 to 9 - 10, did not dissolve scale nor cause any more scale to deposit but the severity of pitting increased.

Slime

Slime in domestic water supplies can cause plugging of transmission lines and objectionable tastes and odors. In industrial water systems, slime results in a loss of operating efficiency, reduction of heat transfer, corrosion, foul odors and deterioration of product quality (60).

Slime deposits in paper mill systems are microbiological or chemical (61). Biological deposits consist of large numbers of bacteria, fungi and/or yeasts together with fines and crystalline material. Bacterial slimes may be gray-white, yellow, orange-brown or even black in color. Fungi usually contribute to slimes only in conjunction with bacteria. Algal slimes are blue-green to green in appearance and will only grow in the presence of sunlight (60).

Chemical or inorganic slime deposits are usually found to contain pitch, alumina, clays, hydrated silica resins, iron sulfides and fine fibers. Most paper mill slimes are combinations of microbiological and chemical material.

The required nucleus for the agglomeration of slime deposits is considered to be the bacterial cell. Studies by Opperman (61) show that fimbriated bacteria may be responsible for the growth of slime deposits because of the extremely fine protein fibrils or fimbrial which extend beyond their capsules and could, therefore, be in a better position for attachment to fibers and other organisms. In support of this theory, slimes from 51 mills were examined with the result that 83 percent contained fimbriated bacteria.

The advent of the closed system in paper mills brought with it a great increase in microbiological problems as a direct result of the concentration of nutrients, formation of stagnant areas and close contact for extended periods with different genera of organisms. Among the organisms that reportedly achieved major importance in paper mills because of the use of closed systems are (62):

1. The nonsporeformers such as Flavobacterium, Pseudomonas and Enterobacter.

2. Aerobic sporeformers such as the Bacillus species.

3. Anaerobic nonsporeformers such as the sulfate reducers.

4. Yeasts and molds such as Penicillium and Aspergillus.

In addition to these, Clostridium organisms have been in 51 percent of 300 samples examined in counts ranging from 100 to several thousand per milliliter or gram of sample. Clostridium species are anaerobic, heterotrophic, sporeforming bacteria which produce large amounts of gas and putrefactive odors such as hydrogen sulfide which is also corrosive. Some species are cellulose decomposers and can form slime under anaerobic conditions. In paper mill systems, the anaerobic conditions required by Clostridium species can be found under slime layers formed by other bacteria, under scale or corrosion products and at the bottom of slurries of such materials as clays, starches and proteins.

Slime deposits may consist not only of bacterial colonies but also may contain fungal hyphae matted together with fibers and debris. C. Wang (63) reported on the species and frequency of the fungi found in representative pulp and paper mills in New York State. Among the most abundant in species and number were the Fungi Imperfecti, especially Aspergillus niger and Aspergillus fumigatus.

The solution of problems created by slime growths involves either the use of mechanical or chemical methods or both. Often, mechanical cleaning can prove to be satisfactory, especially when chemical treatment is expensive and without permanent effect (64). In either case, the best answer to a slime problem must be low in cost, safe, noncorrosive and effective against a wide range of organisms throughout the entire system while avoiding substantial labor costs (60).

The common name for chemical agents used to control slime growth is slimicide. In the pulp and paper industries, a large number of slimi-

cides are in constant use and several of these are fairly effective in meeting the requirements for slime control previously discussed. Among these are the quaternary ammonium compounds, chlorinated phenols, some amines, organo-sulfur compounds, and silver compounds.

Slime growths in pipelines carrying fresh water are due to outgrowths of fresh water organisms which can be treated effectively with chlorine at doses of 9-12 ppm or with copper sulfate at 9-18 ppm. Although copper sulfate seems to be more effective than chlorine, the differences in cost of $71.65/metric ton ($65/ton) for chlorine and $170.86/metric ton ($155/ton) for copper sulfate is favorable to chlorine. In long conduits or in systems which are not very accessible, chemical treatment is often resorted to as cheaper and more practical than mechanical cleaning. Before a chemical treatment is chosen, however, a thorough study of the organisms causing the difficulty should be made and the most effective treatment used. Other conditions must also be ascertained. For example, if the alkalinity of the water is high, copper sulfate may be relatively ineffective. In open ditches or conduits, sunlight may render chlorine useless. Other chemicals such as the chlorinated hydrocarbons should be used with caution not only because of tastes and odors, but because of possible toxicity (65). The corrosiveness and other damaging effects of oxidizing chemicals such as calcium hypochlorite in the case of metal pipes and screens may also preclude their use in certain systems.

Product Quality and Production Rates

Water reuse in paper mills tends to decrease product quality and decreases the drainability of the sheet during formation as a result of the increased concentration of finely dispersed particles such as clay. These problems can be partially overcome by using drainage aids. The term drainage aid is widely used in industry but not well defined. A drainage aid is a high molecular weight polyelectrolyte which improves water removal. This improvement may take place at various points during the papermaking process not always only on the forming section (66). Improved water removal can be directed toward various objectives including:

1) increasing production, 2) lower steam consumption, 3) improved formation, 4) improved ply-bonding in multi-ply sheets and 5) extended use of less expensive raw materials.

The theoretical background and mechanism of drainage aid has been discussed in a recent paper by Edward Strazdins (67). He discussed the work by LaMer and his co-workers which led to the conclusion that the bridging of particles by high molecular weight polymers is the principal mechanism in producing flocculation. In this type of polymer-solid interaction, only segments of the polymer attach first by forming physical or electrostatic bonds. The remaining free end of the polymer then adsorbs onto another particle that has a free adsorption site. Formation of the polymer bridges can occur even against appreciable electrostatic charge barriers. This type of mechanism is predominant in effecting flocculation and retention with anionic polyacrylamides.

The theory of the bridging mechanism only applies to finely dispersed particles such as clay. However, for grossly different systems, such as fiber suspensions, it is not immediately clear to what extent these concepts can be applied to explain the retention and fiber flocculation mechanisms. In a fiber system, the surface charge of the treated fiber played a major role. If the charge of the system is low, the established bonds between the adsorbent and adsorbate have a better chance to survive the disruptive action of hydrodynamic shear. Under conditions where the final charge of fiber remains high (either on the negative or positive side), retention of emulsions becomes increasingly difficult. The established networks are easily disrupted, the desorbed particles bear the same charge as fibers and electrostatic repulsion prevents readsorption. Best retention of a cationic size emulsion is effected when the system is near the isoelectric point. To maintain this condition, additional cationic polymer must be added. To effect maximum retention in the mill, the cationic emulsion-type sizing agents must be introduced beyond the point of severe agitation. The best points of addition are usually near the machine headbox (67).

Water removal is, perhaps, the most serious factor limiting machine speed today. Among the important factors in this problem are the viscosity of water and the need for fibrillating and swelling cellulose fibers in order to develop fiber bonding and paper strength. It is difficult to imagine a method whereby the viscosity of water can be significantly reduced. The effect of increased temperature, presently employed in some parts of the industry, is limited and higher temperatures reduce swelling of the fiber, reduce papermakers' hydration, and cause substantially lower strength. Significantly greater machine speeds and faster drainage will be attained in the future mainly by reduction in beating, refining and fibrillation, and by increasing use of synthetic fibers. The simultaneous requirements for stronger and lighter weight paper will demand that more and better additives of several types be used in such paper (68).

Derivatives of polyacrylamide and polyethylenimines are rapidly gaining in importance as retention aids. Both form complexes with cellulose. The polyethylenimines appear to form salts with the carboxyl group of cellulose fiber in a neutral or slightly alkaline stock suspension while the polyacrylamides appear to be bound to the fiber by "aluminum mordanting action" under acid conditions (69). While both types of additives cause retention, the polyethylenimines have the added advantage of causing improved flocculation, increased drainage and wet strength. Chemical manufacturers are spending considerable effort on programs directed toward their improvement on introduction to the industry.

According to the report of John W. Swanson (68), the addition on the order of 250 g/metric ton (0.5 lb/ton) of certain cationic polymers such as polyamines and anionic high molecular weight polyacrylamides to beater pulp will significantly increase drainage rate and freeness of fiber slurry and removal of water at the presses.

According to the current survey by A. W. Dyck (70), the use of retention and drainage aids shows rapid growth in the papermaking industry. The

use of retention aids results in substantial chemical savings that amount to as much as 15 percent of the wet end additives and reduces stream pollution by retaining fines and filler in the sheet that would ordinarily be lost in the mill effluent. In addition to providing these benefits, drainage aids contribute markedly to an increase in productivity by increasing the rate of water removal on the Fourdrinier and permit a significant reduction in the energy required in the drying operation. The latter is particularly important in today's insufficient papermaking capacity and the present energy crisis.

The growth in the use of retention and drainage aids has been triggered by ecological pressure (71). Mills which previously did not use retention aids suddenly felt themselves forced to do so in response to pressures to reduce stream pollution. The use of retention aids is additionally stimulated by a growing interest in recycling and the need to operate the recycling process under conditions leading to a goal of zero discharge of effluent. In this connection, many mills also use retention and drainage aids in save-alls, machine headbox and clarifiers where these chemicals act as flocculants to reduce pollution loads from paper mill effluents.

The use of retention aids was also justified on the basis of economics. As a retention aid, polyacrylamide performs its nominal task of increasing dry strength and also results in greater retention of fines and faster drainage of water on the wire (70). One must balance these advantages and the rather high cost of the polymer against the lower cost of many other available dry strength additives, and against other methods of increasing dry strength (more beating, stronger pulp, etc.). However, in the final analysis a polyacrylamide resin may be the most economic alternative because: 1) a smaller percentage of polyacrylamide may impart the same degree of dry strength as larger amounts of starches and gum, and 2) polyacrylamide can result in higher levels of dry strength properties than other additives regardless of the amount used.

SECTION V

MANUFACTURING PROCESS AND REUSE FACILITIES

MANUFACTURING PROCESS

Big Chief Roofing Company manufactures organic felt, a thick, absorbent, paper mat which is suitable for saturation with asphalt to form shingles and other roofing products. Waste paper and wood flour are the basic raw materials used in felt manufacturing. Two grades of waste paper are used in equal portions at Big Chief. These are mixed paper and corrugated. The mixed paper is a standard grade of waste paper, which as its name implies, includes any paper product ranging from milk cartons to carbon paper. Corrugated paper is also a standard grade of waste paper which includes any type of cardboard ranging from that found in heavy corrugated boxes to that found in cereal boxes. The wood flour is sawdust that has been ground fine enough to pass through a twenty mesh screen.

The felt is composed of approximately 75 percent waste paper and 25 percent wood flour. The fibers from the waste paper bond together to give the felt the tensile strength necessary for further processing and the wood flour provides bulk and porosity necessary for asphalt penetration. The process is diagramed in Figure 1.

Approximately 30 tons/day of waste paper are transported in bales from the storage area to a paper beater (hydrapulper) where the paper is blended with water from the white water pit to produce a pulp of approximately 3 percent consistency. Live steam is injected in the beater to aid in pulping. For the initial stages of the project, a Shartle Dilts breaker beater equipped with a bed plate fitted with 2.38 cm (15/16 in.) holes to allow continuous operation was used to produce the pulp from the waste paper. Pulp, which is beaten sufficiently to pass through the holes in the bed plate, flows from the beater to the stock chest. In

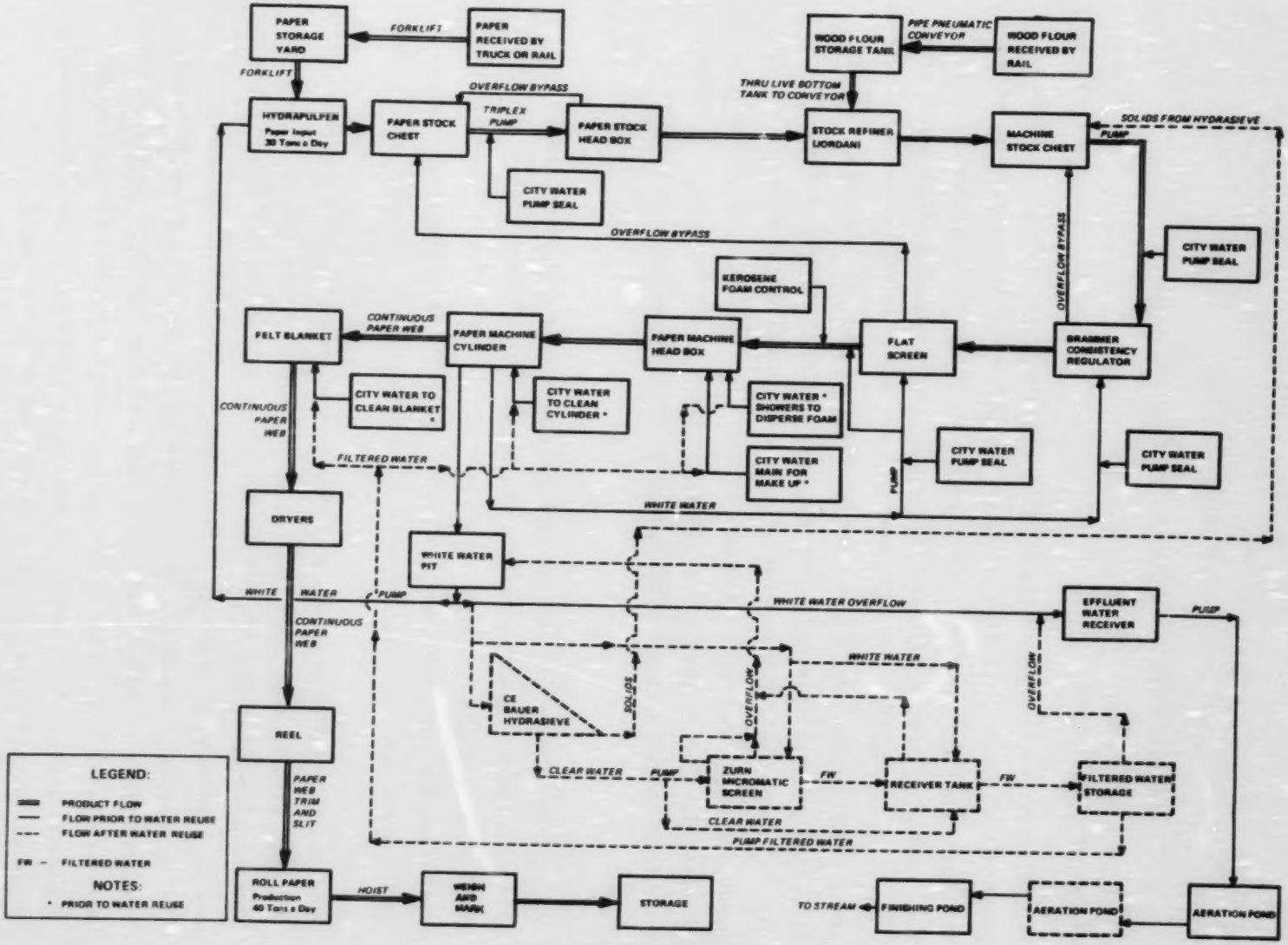

FIGURE 1. PROCESS FLOW DIAGRAM

the latter stages of the project, the paper beater was replaced with a hydrapulper. The hydrapulper is driven by a 149.2 kw (200 Hp) electric motor and has a capacity of 68 metric tons/day (75 tons/day). Metals, rocks, plastics, and wire are removed automatically. The pulp from the beater (hydrapulper) flows to two paper stock chests with dimensions of 3.05 x 3.05 x 9.14 meters (10 x 10 x 30 feet) which are continuously agitated. The pulp is pumped from the chests to a headbox which utilized a sliding weir to control the flow of pulp to the Jordan refiner. (Big Chief uses a Miami, Number 2, Jordan Refiner to refine and thoroughly mix the pulp and wood flour). At the inlet of the refiner, approximately 9.07 metric tons (10 tons) of wood flour per day are added to the pulp. The wood flour is transported to the mill, in bulk form, by rail. A pneumatic pipe conveyor empties the box cars into the wood flour storage tank. A screw conveyor, with a Reeves variable speed drive, delivers the proper amount of wood flour to the inlet of the Jordan refiner. The mixture (stock) leaves the refiner and flows into the machine stock chest. The stock is pumped from the machine chest to a Brammer differential pressure consistency regulator which brings the stock to a consistency of 2.5 percent. An adjustable weir on the consistency regulator allows the proper amount of stock to flow by gravity to a headbox where water from the fan pump dilutes it to 0.6 percent. The diluted stock (furnish) flows from the headbox to a 14 plate Impco flat screen fitted with 0.13 cm (0.05 in.) slots. The particles which do not pass through the screen are returned to the machine stock chest for further refining. The furnish flows from the screen to the headbox of the cylinder vat. The headbox utilizes a series of baffles to distribute the furnish evenly across its width. The furnish then enters a direct flow, single overflow, cylinder vat manufactured by Black Clawson.

The forming cylinder is 1.52 M (60 in.) in diameter, 2.29 M (90 in.) long, and is covered with a 14 x 20 mesh stainless steel wire. As the forming cylinder rotates, water from the furnish flows to the inside of the cylinder depositing a fiber mat on its periphery. The mat is removed

from the cylinder by the couch roll and is transported by a woven fabric (pickup felt) over a suction box, a suction roll and finally through the press section. In sheet couching and transfer, the pickup felt is the medium which removes the sheet from the forming cylinder and conveys it from one water removal device to the next.

Water removal from the stock suspension is accomplished in great quantities as the sheet is formed and pressed. The stock suspension is approximately 0.6 percent oven dry in the cylinder vat, 13 percent oven dry after couching and 43 percent oven dry leaving the press section. To permit this rapid dewatering, the pickup felt must be porous enough to allow water to be drawn from the sheet, through it and into the suction box or suction roll. The felt also cushions the sheet during couching and pressing. Failure to provide adequate cushioning can cause the sheet to crush or rupture.

The pickup felt does not have constant characteristics throughout its life. It is repeatedly compacted and allowed to expand by passage through the water removal devices and is gradually filled with paper fibers, pigment, dirt, grit and slime. Throughout its life, the felt tends to become less porous and looses its compressibility. Ultimate failure of the felt usually occurs when holes develop or it becomes so plugged and firm that the paper sheet crushes. To obtain a long and uniform felt life, Big Chief employs a number of felt conditioning devices such as a felt whipper, felt showers, worm roll and a suction box. These all help keep the felt as clean and fully conditioned as possible. The adjustable felt whipper roll and the tail roll are 17.78 cm (7 in.) diameter, fully wormed rolls. These rolls serve to maintain the original felt width, prevent wrinkles, condition the felt and loosen foreign materials for easier removal. After the worm roll, a water shower saturates the felt from the side which contacts the wet sheet, called the sheet side. Another shower, after the whipper, washes the felt from the opposite side removing the particles loosened by the whipper.

The felt whipper employed at Big Chief is 35.56 cm (14 in.) in diameter with four, 5.08 cm (2 in.) diameter brass bats. It rotates at 290 rpm, striking the sheet side of the felt. The force of the blows is controlled by adjusting the wet felt whipper roll. The intensity of the blows will determine the wear it induces on the felt. Very intense blows will cause excessive wear. The felt whipper conditions the water saturated felt by mechanically beating it to loosen contaminating foreign material. Striking the felt with rapid blows separates entrained foreign particles from the felt and suspends these particles in the saturating water.

After a final felt shower, the felt passes over a suction box. The suction box has a 1.91 cm (3/4 in.) slot and pulls a vacuum of 0.07-0.17 kg/cm^2 (2-5 in. of mercury) depending on the porosity of the felt. The suction box creates a 0.21-0.28 kg/cm^2 (3-4 psi) vacuum on the sheet side of the felt drawing water and the foreign material entrained in the water into the suction box.

The sheet is further dewatered by a 40.64 cm (16 in.) diameter, 1134 kg (2500 lb) press roll that applies 7.87 kg/cm^2 (112 psi) pressure to the sheet. Under the press roll there is a vacuum roll which is subjected to a 0.70 kg/cm^2 (10 psi) to 1.05 kg/cm^2 (15 psi) vacuum. After pressing, the sheet is dry enough to support itself and enters the dryers without aid of a supporting fabric.

The dryer section is composed of 67 steam heated dryers and a hot air system all housed in an open hood. The dryers are 0.914 M (3 ft) in diameter and are mounted in two tiers. They are heated to approximately 138°C (280°F) by steam at 3.52 kg/cm^2 (50 psig). The hot air is transported by a duct which runs the length of the dryer section. A series of headers take the air from this duct and distribute the air evenly across the width of the machine. The headers are located in every dryer pocket and are fitted with 1.91 cm (3/4 in.) holes on 12.70 cm (5 in.) centers. The sheet enters the dryers at 57 percent moisture and leaves at 3 percent moisture. After drying, a finish is

pressed on the sheet with the calender stack. The calender stack consists of two 25.40 cm (10 in.) diameter steel rolls which exert a 1.76 kg/cm^2 (25 psi) nip pressure on the sheet. The felt is then trimmed, rewound, and stored for further processing into saturated and coated products.

REUSE FACILITIES

Total water use in the process prior to this study averaged 7.89 1/sec (125 gpm) or 17,170 M^3 (4,536,000 gal) per month of which 3,270 M^3 (864,000 gal) are lost by evaporation in the process, and 13,900 M^3 (3,672,000 gal) are discharged to the treatment system. The fresh water purchased from the city enters the system through the shower nozzles, pump seals, periodically from water added to fill the cylinder vat during start-ups (approximately 15 M^3 (4000 gal)), and through hoses to wash the equipment and floors.

The dilution water in the furnish is drawn into the paper machine cylinder. This water is reused as dilution water at the consistency regulator and the flat screen. Excess cylinder water and water extracted from the organic felt mat by the suction roll and press section, and water used for cleanup flows to the white water pit. From the white water pit, water is pumped to the beater. (Prior to water reuse, excess white water was discharged to the treatment system).

In order to control pollution from the paper making process, and to conserve water, Big Chief Roofing Company installed water reuse facilities. The water reuse facilities were designed to screen white water to remove the suspended solids so that it could be used in place of fresh water. The facilities include a Bauer hydrasieve, a Zurn micromatic screen, a filtered water storage tank, and the required pumps, pipes and other appurtenances. These screens can be used individually or in series depending on the required water quality.

The hydrasieve is an inclined, stainless steel screen over which the wastewater cascades. It was designed to remove the gross solids, protect the micromatic screen, and possibly provide water of sufficient quality for reuse. The design of the hydrasieve allows removal of solids with a particle size of approximately 170 microns which is one-half as large as the wire spacing. The hydrasieve has a flow capacity of 9.46 l/sec (150 gpm). The screening surface has the rugged durability necessary to handle the gross particles which may be swept into the white water pit and hence, be pumped into the process potentially damaging the micromatic screen.

The Zurn micromatic screen is a horizontal rotating drum type strainer. The periphery of the drum is covered with an extremely fine, 35 micron, stainless steel woven fabric. The white water enters the center of the partially submerged 1.22 M (4 ft) drum through an open end and flows outward through the straining media. The debris remains on the interior surface of the drum and is transported upward over a stationary waste collector located inside the drum above the water level. A row of water jets positioned directly above and outside the drum uses a small percentage of product water to flush the fibers and other solids from the interior surface of the drum into the waste collector and then into the white water pit.

The effluent from the micromatic screen and/or hydrasieve is pumped to a 113.6 M^3 (30,000 gal) filtered water storage tank. This water is subsequently reused in the showers and for cleanup. The suspended solids with a particle size greater than 170 microns removed by the hydrasieve are returned to the machine chest.

SECTION VI

EXPERIMENTAL ANALYSES AND PROCEDURES

All analyses, with the exception of solids, bacterial, corrosion, and product quality were performed according to the 13th edition of Standard Methods for the Examination of Water and Wastewater (70). Solids were determined gravimetrically after separation from the waste by centrifugation and drying. Corrosion tests were performed following procedures as outlined in the American Standards for Testing Materials (71). To determine the effects of water reuse on product quality, samples of the product were sent to the Chicago Paper Testing Laboratory. All tests on product quality were performed according to the Technical Association of Pulp and Paper Industries Standards. The routine water analyses were performed in the Sanitary Engineering Research Laboratory in the Department of Civil Engineering and Environmental Science at the University of Oklahoma. A limited number of solids and product quality tests needed for operational control, were performed in the quality control laboratory at Big Chief Roofing Company. Analyses and measurements performed as routine tests included: alkalinity, chemical oxygen demand (COD), chloride, conductivity recorded as TDS, pH, and solids determination. Periodic tests included bacterial control and temperature.

BACTERIAL CONTROL

In order to control bacterial slimes and to determine the effects of various slimicides and chemicals on bacteria in the water being reused, a modified sensitivity disc technique was employed. Absorbent discs, 7 mm in diameter, were cut from millipore filter pads and saturated with solutions containing known concentrations of the slimicidal agents to be tested. Excess liquid on the outer surface of the discs was removed by placing them for one minute on an absorbent paper mat. The discs were then placed on agar plates which had previously been seeded with enough bacterial inoculum from the reused water to produce a smooth lawn. The

seed consisted of 0.5 ml of a 0.01 dilution of water from the paper reprocessing system. The agar plates used were glucose nutrient agar buffered to pH 7. The plates were incubated at 37°C (98°F). Controls were run by placing absorbent paper discs saturated with distilled water on the agar plates.

A second technique was employed in which 100 ml batch samples of reuse water and known concentrations of slimicide were placed in 250 ml shaker flasks and maintained at 48°C (118°F) for 48 hours. These conditions simulated existing plant conditions while operating at 85 percent water reuse. Plate counts were made to determine the effectiveness of the slimicide.

CHLORIDE

The mercuric nitrate method was used in the determination of chloride.

CORROSION

In order to determine the magnitude of the increase in corrosion, both laboratory and full scale studies were performed. All tests for corrosion followed the American Standards for Testing Materials.

The test coupons were composed of materials used in construction of the plant such as mild steel, stainless steel, bronze and cast iron. The coupons were finished to approximately a 120 grit surface by mechanical grinding. The average size of a coupon was 1.9 x 1.9 x 0.15 cm. The cast iron and mild steel coupons were cleaned to bare metal using reagent grade concentrated hydrochloric acid inhibited with five percent stannous chloride and two percent antimonious oxide by weight. After immersing in the above solution, with vigorous stirring for 25 minutes, the coupons were washed and rinsed with distilled water, placed in an acetone bath, air dried and weighed to the nearest 0.0001 gram. The test coupons were placed in water at the plant that was either quiescent, moderately turbulent or highly turbulent. A nylon line was used to suspend the coupons in water. The tests were run for a period of 15 to 30 days. Then the coupons were removed from the system, dried, weighed and cleaned as before and reweighed.

Corrosion tests were also performed using a laboratory model. The studies were performed using 250 Erlenmeyer flasks containing 150 ml of waste which was agitated in a water bath shaker that held nine flasks. The shaker, operated at an amplitude of 3.81 cm (1.5 in.) and a frequency of 110 cycles per minute, was used to simulate the turbulence in the plant. The temperature of the flasks were maintained between 46 and 48°C (115-118°F) which was the average temperature of the water in the plant. The clean and preweighed coupons were suspended above the bottom of the flasks with a piece of nylon string. The flasks were emptied and filled with new waste every four days. During the four day period, distilled water was added to replenish the water lost from evaporation. The pH of the wastes was measured. The tests were run for a period of 15 to 30 days after which the coupons were removed from the flasks, cleaned as before, then weighed. The weight loss was determined and converted to corrosion rate expressed in milligrams/square meter/day using the following formula:

$$Rmdd = 100{,}000 \frac{Wo - Wf}{AT}$$

Where: Rmdd = corrosion rate
Wo = original weight in grams
Wf = final weight in grams, after cleaning
A = exposed area of the coupons in square centimeters
T = duration in days

PAPER TESTING

In order to determine the effect of water reuse on paper quality at Big Chief, a series of product samples was submitted to the Chicago Paper Testing Laboratory for evaluation. The samples were selected according to the Technical Association of Pulp and Paper Industries (TAPPI) standard T-4000. At this laboratory, the samples were conditioned in accordance with TAPPI standard T-402 os-70, defining the standard conditioning and testing atmosphere for paper, board, pulp handsheets and related products. The following tests were performed according to TAPPI standards:

1. Weight per unit area (basis weight or substance) of paper and paper board, T-410 os-68.

2. Thickness (caliper) of paper and paper board, T-411 os-68.

3. Air resistance of paper (porosity), T-460 os-68.

4. Bursting strength of paper, T-403 ts-63.

5. Tensile breaking strength of paper and paper board, T-404 ts-66.

6. Stretch of paper and paper board, T-457 m-46.

7. Internal tearing resistance of paper, T-414 ts-65.

Tests were performed in the quality control laboratory at Big Chief Roofing Company for tensile strength, kerosene absorption, basis weight and moisture content. With the aid of these tests, the speed of the machine and the flow of waste paper and wood flour to the cylinder vat were regulated since these factors controlled the porosity, strength, basis weight and moisture content of the sheet.

SODIUM

The flame photometric method was used in the determination of sodium content. A model DH Beckman quartz spectrophotometer was used in the analysis.

SOLIDS

The centrifuge technique was used to separate the filterable and nonfilterable solids since the nonfilterable solids include a high percentage of clays, fillers and fines. These can only be removed by centrifugation or filtration through a millipore filter. Filters with openings of only a few microns plugged rapidly. Sample sizes that could consistently be filtered through the millipore filters were too small to give reproducible results. Therefore the following procedure was used for solids determinations:

Filterable Solids

1. Thoroughly mix the sample and transfer a 40 ml aliquot into a 50 ml centrifuge tube.

2. Centrifuge at 10,000 rpm for 10 minutes in a Sorval super-speed centrifuge.

3. Transfer 20 ml of the supernatant to a predried, tared, evaporating dish.

4. Evaporate to dryness at 103°C (217°F).

5. Cool in a desiccator and weigh.

6. The total filterable solids are reported in mg/l as the increase in weight due to the residue after evaporation.

7. The residue was ignited at 600°C (1112°F) in a muffle furnace for two hours. The loss of weight after ignition was reported as mg/l filterable volatile solids. The residue was reported as mg/l filterable fixed solids.

Nonfilterable Solids

1. Mix the sample thoroughly and transfer a 40 ml aliquot into a tared evaporating dish.

2. Evaporate to dryness in a drying oven at 103°C (217°F).

3. Cool in a desiccator and weigh.

4. The increase in weight due to the residue after evaporation was reported in mg/l as total solids.

   a) Ignite the total solids residue at 600°C (1112°F) in a muffle furnace for two hours.

   b) The residue remaining after ignition was reported as mg/l total fixed solids. The loss of weight after ignition was recorded as mg/l total volatile solids.

5. The nonfilterable volatile solids were obtained by subtracting the filterable volatile solids from the total volatile solids. The nonfilterable fixed solids were obtained in a similar manner.

SECTION VII

RESULTS AND DISCUSSION

This study was divided into three phases--no water reuse (conventional), 85 percent water reuse and 100 percent water reuse. In this section, the data from the three phases are presented and the results are compared. This comparison sets forth:

1. The effects of water reuse on product quality.
2. The effects of water reuse on process water quality.
3. The problems resulting from water reuse.
4. A cost effective analysis.

EFFECTS OF WATER REUSE ON PRODUCT QUALITY

When the role of water in the organic felt making process is examined, it is reasonable to expect that water reuse will have little or no effect on product quality. Water acts as a mechanical transport and dispersion medium which allows pumping of the pulp slurry and forming of the sheet. Water is also used as a cleaning agent in conditioning the pickup felt and to carry away fine solids.

It is reasonable to expect a layer of fines and clay type fillers to concentrate when water is reused. This tends to decrease the porosity of the organic felt which in turn decreases the absorption of asphalt, thereby adversely affecting its use as a roofing product. Wood flour, which has greater size and more absorption, can replace the fines so that a bulky, porous sheet can be formed. Control of the flow of wood flour into the product then helps compensate for the increased concentration of fines.

The most noticeable effect of water reuse on paper quality is a slight increase in the number of imperfections in the sheet. These imperfec-

tions are in the form of crushing and slime spots or holes. Crushing is an imperfection in the formation of the sheet. It occurs when pressure is applied to the sheet to remove free water and the water is unable to move vertically. In this case, hydraulic pressure forces the water to move horizontally disrupting sheet formation. Crushing is normally caused by a pickup felt which is not porous enough to allow the water to be squeezed from the sheet, or by too high a nip pressure or uneven nip pressure at the couch roll or press section. At Big Chief, crushing normally occurs at the couch roll and is usually caused by localized plugging of the pickup felt.

Localized plugging of the felt often occurs when nozzles of the felt conditioning showers plug. This reduces the effectiveness of felt conditioning in that area. Plugging of felt showers is more prevalent when filtered white water is used in the showers than when fresh water is used. Increased sheet crushing is, therefore, an indirect result of water reuse. Its extent can be minimized by regular cleaning and checking of the felt conditioning showers.

In order to determine the effects of water reuse on paper quality, 40 product samples were submitted to the Chicago Paper Testing Laboratory for evaluation. Twenty samples were submitted during the period of no water reuse and twenty during 85 percent water reuse. The results of the statistical analyses of the data from these tests, recorded in Appendix A, are listed in Table 1. Based on these analyses, there were no significant differences between the various product quality parameters at the one percent level of significance. Since there was no significant degradation in product quality at 85 percent water reuse and the product quality control tests performed at Big Chief during zero discharge indicated no significant change, tests were not performed at the Chicago Paper Testing Laboratory during 100 percent water reuse.

TABLE 1. COMPARISON OF ROOFING FELT QUALITY
(85% WATER REUSE AND NO WATER REUSE)

Parameter	Mean		Standard Deviation		t
	85 percent water reuse	No water reuse	85 percent water reuse	No water reuse	
Basis weight, g/M^2	504	494	17.6	16.2	1.85
Caliper, mil	68.6	68	2.1	2.5	.81
Mullen, pt	38.1	38.2	2.4	2.9	.12
Tensile strength MD, g/cm	7232	7500	678	750	1.17
Tensile strength CMD, g/cm	4278	4178	262	393	0.94
Elongation MD, percent	6.5	6.5	0.1	0.3	0.0
Elongation CMD, percent	7.5	7.5	0.4	0.6	0.0
Tear Elmendorf MD, grams	305	319	32	27.7	1.46
Tear Elmendorf CMD, grams	359	376	44	47.2	1.16
Porosity Gurley, sec./100 cc	4.7	4.7	0.5	0.6	0.0

EFFECT OF WATER REUSE ON PROCESS WATER QUALITY

Prior to this study the water demand at Big Chief Roofing was approximately 7.86 l/sec (125 gpm) resulting in a waste discharge of 6.31 l/sec (100 gpm) and evaporative and other losses of 1.55 l/sec (25 gpm). During the initial stage of this study, the effluent from the mill was reduced to approximately 0.95 l/sec (15 gpm) which represents an 85 percent reduction. During the latter stages of the study, more extensive water reuse was practiced resulting in a further reduction of waste discharge to approximately 15.14 M^3 (4000 gal) per week which was discharged at the time of clean-up. This approaches 100 percent water reuse or zero discharge. When the system is operating at zero discharge, 0.76-0.88 l/sec (12-14 gpm) is required to replenish the water lost by evaporation from the dryers. The decrease in consumptive losses (25 gpm to 12-14 gpm) from the initial to the final phase of the study was due to in-plant changes.

The water quality in the system fluctuates considerably since a small change in flow can result in a significant dilution or concentration of the chemicals in a system where water use is low. Gross additions of fresh water, such as during start up, drastically dilute the chemicals in the system. The chemical quality of the water in the system is also affected by the composition of the waste paper. The waste paper used at Big Chief Roofing is composed of a wide range of paper products. Each bale of waste paper has different ratios of various products depending on the paper available from the distributors. The composition of the various paper products varies considerably in fiber characteristics, fillers, coatings, ink, glue, etc., which in turn affects the water quality in the system. For example, certain high quality paper is composed of 30-35 percent by weight clay with particle sizes less than 10 microns. These particles are dispersed throughout the system and cannot be removed by screening or other physical processes. Therefore, they concentrate in a closed system resulting in a high nonfilterable fixed solids concentration. Binders, fillers, and other sizing chemicals can also affect the dissolved solids content of the system.

Other grades of paper such as newsprint, have no binder or fillers added, thus their use will result in lower dissolved and suspended solids concentrations in the reprocessing system, but if too much newsprint is used a weak sheet is produced. The cleanliness of the bales also affects the composition of the system. The waste paper bales contain dirt, grit, plastic, metal, styrofoam, etc. These foreign materials obviously affect the chemical composition of the system.

A summary of the major characteristics of wastewater during the period of no water reuse, 85 percent water reuse, and 100 percent water reuse, is given in Table 2. The data from which this summary was prepared are included in Appendices B-D. When water reuse is practiced, chemical concentrations increased considerably reaching equilibrium after 6 to 10 days.

At equilibrium the concentration of filterable fixed solids increased from approximately 320 mg/l at no water reuse to 1150 mg/l at 85 percent reuse to 1960 mg/l at 100 percent reuse. The dissolved solids increased from 1530 to 5100 to 8210 mg/l at 0-, 85-, and 100 percent reuse, respectively. The COD increased from 1590 to 5560 to 8780 mg/l during the same periods. The concentration factors ranged from 1.1 to 3.5 for 85 percent reuse and from 1.9 to 6.2 for 100 percent reuse. These increases enhance the available food supply for bacterial growth and the decrease in water use increases the retention time in the system, thereby giving the bacterial slimes time to form. The concentration of the aggressive ions, such as chlorides and other ions which are measured by an increase in conductivity (TDS), contribute to the acceleration of corrosion rates.

PROBLEMS RESULTING FROM WATER REUSE

Potential problems that are consequences of the decreased water quality are: corrosion, decreased felt life, sheet crushing, slime deposits, foam, scale, sludge deposits, plugging of screens and showers in the paper forming area and the water cleaning system.

TABLE 2. SUMMARY OF WASTEWATER CHARACTERISTICS

Parameter	No Water Reuse		85% Water Reuse			100% Water Reuse		
	Mean	Standard deviation	Mean	Standard deviation	Concentration factor	Mean	Standard deviation	Concentration factor
COD mg/l O_2	1587	311	5564	458	3.50	8781	203	5.53
Chloride mg/l	52.6	16.0	91.2	9.6	1.73	183.2	6.1	3.45
TDS mg/l	394	105	1262	221	3.20	1960	51	4.97
Filterable fixed solid, mg/l	319	160	1150	145	3.60	1960	9.6	6.14
Filterable volatile solid mg/l	1214	360	3947	420	3.25	6250	231	5.15
Nonfilterable fixed solid mg/l	197	69	211	61	1.07	370	41	1.88
Nonfilterable volatile solid mg/l	243	54	393	156	1.62	830	180	3.42
pH	6.8	0.2	6.1	0.3		6.4	0.1	
Alkalinity mg/l $CaCO_3$	279	64	568	67	2.04	1081	10	3.87

Corrosion

With the increased concentration of dissolved solids due to water reuse, the corrosion rates were expected to increase. In order to determine the magnitude of the increase, coupons were placed at strategic points in the system and in a laboratory model. The results of the corrosion tests are given in Table 3. (Data given in Appendix E.)

TABLE 3. SUMMARY OF CORROSION RATES, Rmdd

($mg/M^2/day$)

Coupon Material	No water reuse	85% water reuse	100 % water reuse
Brass	1.87	5.10	16.83
Stainless steel	0.02	0.04	0.07
Mild steel	32.75	74.44	88.75
Cast iron	30.10	50.95	85.40

As expected the results shown an increase in corrosion rates when water reuse is practiced for all materials tested. The practical significance of the increase has not been determined since there has not been any significant increase in the cost or frequency of replacement of parts and equipment at Big Chief to date.

Corrosion is a significant problem in systems where the pH is not controlled. In a paper reprocessing plant which practices water reuse, the pH tends to drop as a result of organic acids which are generated from waste paper and wood flour. In a solution with a low pH, hydrogen evolution type of attack is the dominant form of corrosion. Therefore, the control of pH plays an important role in solving the corrosion problem in many systems. This is verified by experience in the Daingerfield Manufacturing Plant in Daingerfield, Texas which also uses waste

paper and wood fiber for the production of organic felt. Water reuse in this plant was imperative due to the unavailability of space for an adequate treatment system. During the initial stages of start up in this plant when complete water reuse was practiced, corrosion problems were almost prohibitory. Large pump casings would be destroyed within a few weeks and pipes and flat metal sheets would last only a few days. Without pH control, the pH would drop below five as a result of the acidic nature of the paper and the decomposition of organic materials into organic acid. By increasing and maintaining the pH at approximately 7.0, the corrosion problem was essentially eliminated. At Big Chief, the pH was maintained at 6.1 $\pm$ 0.4 during water reuse. This required 68 kg (150 lb) of anhydrous caustic soda each day during 85 percent water reuse and 108 kg (240 lb) during 100 percent water reuse. It is, therefore, necessary to monitor and control the pH in the system to avoid corrosion associated with acidic conditions and scale problems associated with basic conditions.

Temperature also plays a role in corrosion. The hydrogen ion activity is greater in high temperature water than in low temperature water. Since the average temperature of the system is about 20-25^{o}C (63-77^{o}F) higher when reuse is practiced than when no reuse is practiced, the corrosion rates were also expected to increase. The temperature effects were not isolated in this study but are reflected in the corrosion data since the coupons were placed in the operating system.

The flow velocity and turbulence are also important factors that affect the corrosion rate. Generally the corrosion rate increases with increasing velocities to a maximum value of 60 M/min (200 ft/min). Any further increase in flow rate results in a decrease in the rate of corrosion. The coupons which were placed in a moderately turbulent or highly turbulent area in the system gave higher corrosion rates than those placed in quiescent areas. Any build up of slime, fiber or other protective films on the surfaces of the coupons was inhibited by the turbulence. The coupons that were placed in a quiescent area gave a lower corrosion rate because in a quiescent media, the protective film prevents further corrosion.

Felt Life

When water reuse is practiced, it is expected to have a detrimental effect on the life of the pickup felt. The filtered white water has a high suspended solids concentration which cannot be removed by the hydrasieve or the microscreen. These particles of foreign material are trapped by the felt, and if the felt cleaning systems are inefficient they may cause plugging. Any increase in bacteriological content of the white water may also lead to plugging problems.

Table 4 represents the life of the pickup felt obtained at Big Chief over the past five years.

TABLE 4. SUMMARY OF FELT LIFE

Condition	Wear, days
No water reuse	75
85 percent water reuse	64
100 percent water reuse	50

To develop this data the felts were grouped according to the conditions which prevailed during the life of the felt, i.e., was filtered white water or city water used for felt conditioning. Felts which were removed because of manufacturing defects, excessive stretching, mechanical failure, etc., were not included in the report. Felts that overlapped the periods of no water reuse and water reuse were also excluded from the report. When no water reuse is practiced, the average felt life is about 75 days. The average felt life is reduced to 64 days when 85 percent water reuse is practiced and to 50 days when the system is closed, i.e., zero discharge. This prevails in spite of the fact that the white water enters the felt conditioning showers at approximately twice the temperature and pressure of the city water. The filtered white water enters the showers at 7.03 kg/cm^2 (100 psi) and 38-54°C (100-130°F) while city water enters the showers at 3.51 kg/cm^2 (50 psi) and 10-21°C (50-70°F).

The felt conditioning showers serve to saturate the pickup felt and loosen the particles of embedded foreign material. The water then serves as a medium to trap and transport the particles which the showers, whipper and worm roll loosen so that they can be removed from the felt by the vacuum box. The manufacturers of modern fabrics recommend shower pressure of 5.27 kg/cm^2 (75 psi) or higher and water temperatures of up to 40°C (140°F) to obtain the best cleaning action of the felt. Although the recommended temperature and pressure were maintained during the period of water reuse, the felt life was shorter than during the period of no water reuse. This was because of the high suspended solids concentration in the filtered white water or plugging of the felt conditioning showers. When a shower nozzle plugs, the area of the felt serviced by the nozzle is left unsaturated which leads to localized felt plugging and hence localized crushing of the mat.

At Big Chief, the nozzles of the felt conditioning showers were cleaned periodically. At the beginning of the study, an average of three nozzles would completely plug and others partially plug each eight hour shift. This problem was primarily due to the unreliability of the Zurn micromatic screen. During the first several months, failure of the trunion bearings and the gear box, and blinding of the screen prevented its use. When the microscreen was not in use, plugging problems were particularly acute. When plugging occurred, as evidenced by crushing of the mat, detergents were used in an attempt to open the felt. If these were unsuccessful, the felt was replaced. When the microscreen was in operation, plugging of the shower nozzles was minimal. This indicates the necessity for matching the shower nozzle opening with the white water screen. The shower nozzle must be considerably larger than the screen opening. Larger nozzles result in high water use for felt conditioning, which, in turn, results in higher pumping costs.

Studies were performed to determine the flow rate required for felt conditioning. The felt conditioning showers were originally equipped with 0.241 cm (0.095 in.) orifice spray nozzles and were later replaced with

0.157 cm (0.062 in.) nozzles. The water used decreased from 4.42 l/sec (70 gpm) to 2.21 l/sec (35 gpm) as a result of the change. The felt life was approximately the same for both conditions indicating that the felt life is independent of the quantity of water used if the quantity required for saturation of the felt is met or exceeded.

Slime

Increased quantities of slime deposits were found in the system at Big Chief during periods of water reuse. As noted in the literature survey, these deposits can produce deleterious effects on product quality and also result in damage to metal components of the system.

Many types of chemical agents, or slimicides, are employed to control slime growths. Quaternary ammonium compounds (QAC) were selected for use at Big Chief because they are effective in low concentrations and are less likely to damage metal components. Since chemicals may exhibit synergism, a series of tests were performed using the following mixtures of quaternary ammonium compounds:

1. Tetradecyl dimethyl benzyl ammonium chloride--25%
2. Dodecyl dimethyl benzyl ammonium chloride--20%
3. Hexadecyl dimethyl benzyl ammonium chloride--5%
4. Inert ingredients--50%

The effective concentration of this mixture, required for control of the slime bacteria present in the Big Chief system, was determined using the sensitivity disc technique. In addition, effective slimicidal concentrations of a commercial slimicide (RX-12), and sodium were also determined. The commercial slimicide contained the following ingredients:

1. Sodium penta chlorophenate--33.8%
2. Sodium 2,4,5-trichlorophenate--8.5%
3. Sodium salts of other chlorophenates--5.9%
4. Sodium dimethyl dithiocarbonate--2%
5. Inert ingredients including solubilizing and dispersing agents--49.8%

The effectiveness of sodium for controlling slime growth was determined since it is added to the system as sodium hydroxide for pH control. The results of the relative effectiveness of the three types of chemicals are presented in Table 5. From these results, it is apparent that the QAC mixture was the best slimicide with respect to control of the bacteria present in the system at Big Chief. The QAC mixture was approximately 100 times as effective as the commercial slimicide and 1000 times as effective as sodium. The concentration of sodium in the system during 100 percent water reuse was 1120 mg/l which is much lower than that required to inhibit slime growth. In order to verify the effectiveness of the QAC mixture, it was tested under conditions similar to those in the process at Big Chief.

TABLE 5. EFFECT OF VARIOUS SLIMICIDES ON BACTERIA

Slimicide	Concentration (ppm)	Effect
Quaternary ammonium compound (QAC) mixture	3	Good zone of clearing
Commercial slimicide (RX-12)	400	Good zone of clearing
Sodium (as sodium hydroxide)	8000	Good zone of clearing

Note: Good zone of clearing defined as no growth to approximately 3-4 mm beyond the edge of the sensitivity disc

Shaker flasks containing 100 percent reuse water were incubated at 48°C (118°F) with 3 ppm of the QAC mixture for one week. The results of this experiment are given in Table 6. The QAC mixture was effective in controlling slime bacteria when used at a concentration of 3 ppm. Concentrations of the compound greater than 6 ppm may lead to foaming problems. Other parameters such as hardness, pH and temperature of the 100 percent reuse water, were at acceptable levels for effective microbial action by the QAC mixture. A summary of these conditions is shown in Table 7. The comparison shows the conditions were suitable for the use of quaternary ammonium compounds. Prior to the termination of the study,

3 mg/l of the QAC mixture was introduced into the system for a short period of time. Tentative results of slimicidal activity measured by total plate count indicated a decrease in bacterial concentrations at less than 50 percent of the cost of the commercial slimicide. The QAC mixture is a relatively inexpensive, noncorrosive chemical which performed well at Big Chief. When compared with other slime control chemicals, it appears to be the best alternative.

TABLE 6. TOTAL BACTERIA PRESENT/ML

Time (days)	QAC mixture (3 ppm)	Control (no QAC)
0	2×10^6	2×10^6
1	1×10^3	1×10^6
2	--	--
3	1×10^2	3×10^5
4	8×10^2	6×10^5
5[a]	--	--
6	50	2×10^5
7	50	1.5×10^5

[a]On day 5, an additional 3 ppm of the mixture was added.

TABLE 7. OPTIMUM CONDITIONS FOR QAC EFFECTIVENESS (74)

Parameter	Desirable	Actual
Hardness	500 ppm or less	346 ppm
pH	6.0 or higher	6.5
Temperature	24°C or higher	48°C

Foam

Foam is another problem which can be accentuated when water reuse is practiced. Foam occurs when air is dispersed in a solution that contains surface active agents. The surface active agents concentrate in the film surrounding each bubble increasing its stability. If the rate of bubbles rising to the surface exceeds the rate at which they break, a surface foam or froth appears.

Fibers and other suspended solids often adhere to the film surrounding the bubble as it rises to the surface. This "froth flotation" affects the concentration of fibers, filler particles, dirt and slime at or near the free water surfaces in the system. Froth flotation is most evident in the white water pit. Water cascading into the pit from suction boxes and rolls, or other sources, entrains air. This entrained air causes froth flotation which forms a mat of fibers, filler particles, dirt and slime on the surface of the pit. Pieces of this mat can break off and be pumped to the hydrasieve or heater. Pieces going to the hydrasieve will be screened into the machine chest, removed by the flat screen and eventually dispersed by the Jordan. Those entering the hydrapulper will be dispersed by the hydrapulper and the Jordan. In either case, the mat will be dispersed before it can cause problems in the cylinder vat. However, froth can form or reform in the headbox or the cylinder vat. This froth can seriously impair product quality by forming holes or spots in the paper.

Air dispersed in paper making stock can cause many problems in addition to the formation of surface foam. Some of these associated problems are: 1) reduction of pump efficiencies and air locking of pumps, 2) interference with drainage of stock on the cylinder molds adversely affecting formation, 3) reduction in the strength of both the wet web and the finished sheet, and 4) promotion of growth of many slime forming microorganisms.

Foam can be controlled by chemical agents or mechanically by sprays. Sprays are commonly used in paper mills to inhibit foam prior to forming of the paper on the paper machine.

There are many commercially available foam control agents that satisfactorily control foam in paper mills. Kerosene is most widely used for foam control since it effectively reduces air entrainment in the system. However, kerosene has a deleterious effect on the felt, the rubber covered rolls, the BOD level and the slime potential. It also presents a fire hazard. In spite of these shortcomings, at Big Chief kerosene has proven to be the most available and economical foam control agent.

Scale

The reuse of process water is frequently limited by the formation of scale or similar encrustations in various parts of the recirculating water system. These deposits can plug filters, screens, wires and forming fabrics. They can block or restrict the flow of stock or water through pumps and pipelines and can build up on the paper machine to the point of causing damage to machine clothing and parts as well as reducing the quality of the paper produced.

Process water from a felt mill utilizing secondary fiber and wood flour contains high concentrations of fine suspended solids, wood, chemicals leached from the recycled fiber, wet-end additives, and broke. All of these can introduce into the recirculating water system materials with scaling potentials. If the water supply has a high calcium hardness, then there is a possibility of calcium carbonate scale. The calcium hardness in fresh water is frequently present in solutions as the bicarbonate. In the water reuse system, the salts are concentrated by evaporation and the carbon dioxide is removed by heat and aeration, thereby resulting in the precipitation and deposition of calcium carbonate. The magnitude of this problem is a function of pH since calcium carbonate is soluble in acids.

Other dissolved salts that may be present in the water supply causing potential scale problems include soluble ferrous and manganous compounds. These compounds can be oxidized and deposited as their insoluble oxides. Water containing these salts supports the growth of iron or manganese utilizing bacteria that contribute additional deposition problems.

Many of the usual paper machine wet-end additives (alum, fillers and pigments used in making the paper from which the recycled fiber is obtained) can contribute to scale problems. Excessive concentrations of alum can lead to the precipitation of aluminum hydroxide which may form a chemical slime, plug wet felts, or form a scale on surfaces exposed to the reused water and concentrated salts. The mineral fillers and pigments used in paper making can build up to rather high concentrations in water reuse systems if retention on the paper machine is relatively low. As the concentration of suspended, nonfibrous solids in the water increases, due to reuse, there is a greater tendency for these solids to form scale deposits.

To prevent deposition of scale in water recycling systems, it is necessary to limit the concentration of scale-forming materials in the recycled process water or to prevent those materials that are present from forming encrustations on exposed surfaces. Limiting the quantity of water recycled by increasing the amount bled off from the system would obviously reduce the concentration of scale-forming constituents, but such an approach is contrary to the goal of more efficient water reuse. Methods that are compatible with the goal would include: velocity control, improved clarification, treatment to remove dissolved solids and use of chemical additives.

The traditional methods of scale control used in treating recirculating cooling water systems have been used in pulp and paper mill white water systems with varying degrees of success. For example, polyphosphates, which have had wide application in industrial water processes, have been used to control scale in white water systems. Polyphosphates are

sequestering agents which help keep metal ions in solution. They are also used as dispersants for solids which may help in controlling solids deposits in water reuse systems. Organic chelating agents such as EDTA can be used to control scale. They form chelates or complexes with polyvalent metal ions and under certain circumstances can prevent precipitates from forming. Dispersing agents of various types such as synthetic organic surfactants, tannins and lignosulfonates can be used if needed to prevent the deposition of suspended solids, including fillers and pigments, as well as materials that might be precipitated from solution. Synthetic organic polyelectrolytes can also be used to control scale in white water systems.

Scale was not a major problem at Big Chief. The pH was maintained slightly above 6.0 which controlled calcium carbonate deposits. Other dissolved salts did not cause significant scale problems. The only significant operating problem resulting from a combination of scale and other deposits was blinding of the Zurn micromatic screen which significantly reduced its throughput. Many cleaning agents such as detergents, caustic soda, phosphoric acid based cleaners, and steam were used to clean the screen. The most successful combination of cleaners was a solution of phosphoric acid followed by caustic soda.

Water Balance

In the design of a water reuse system, it is imperative that water filtering, storage and surge capacities be sufficient to filter and store the excess process water during periods when the flow from the process (supply) exceeds the demand and to supply water to the process when the demand exceeds the supply. Inadequate storage and surge capacities result in wasting water during periods of low water use and the requirement for make-up water during periods of high water use.

As the system at Big Chief was originally designed, it was not possible to obtain zero discharge. The problem with the original system centered around the inherent unsteady operation of the paper beater. Due to the

quality of the waste paper, the beaters operation was constantly interrupted by plugging, cleaning and ragging of the beater. When the system was operating properly, steady state, 15.78 l/sec (250 gpm) of white water was pumped to the beater and 6.31 l/sec (100 gpm) through the hydrasieve and micromatic screen to the clear water storage tank. When the beater was shutdown for cleaning and ragging, the white water pit filled rapidly and overflowed into the effluent receiving pit unless the excess white water could be screened and stored in the filtered water storage tank. Since the hydrasieve and micromatic screens were only designed for 9.46 l/sec (150 gpm), the excess 12.62 l/sec (200 gpm) was wasted. To achieve zero discharge it was necessary to increase the capacity of the screens and to provide additional storage capacity for the white water or to reduce the surges resulting from the unreliable paper beater. At Big Chief, the problem was solved by replacing the paper beater with a hydrapulper. This change decreased the surges resulting in a smoother operation allowing the operators to achieve zero discharge. To assist the operators in maintaining a steady state operation, a stock chest level controller and consistency regulator were also installed. With these equipment changes, the operators can maintain the paper stock chest at a relatively constant level ± 15 cm (6 in.). This differential can easily be compensated for in the existing white water pit and storage tank.

As mentioned above, zero discharge could have also been obtained by increasing the capacities of the screens and the white water storage tanks. At Big Chief this would have required increasing the capacity of the screens to 22.1 l/sec (350 gpm) and doubling the filtered white water storage capacity.

Sludge Deposits

A problem of minor significance was the disposal of the clays, fillers and fines which settled out in the filtered water storage tanks. At Big Chief these solids were disposed of in existing lagoons for waste treatment. In other systems these solids would have to be retained in the system, removed by placing on the product or transported to an ultimate disposal facility such as a sanitary landfill.

Preliminary studies were performed to determine the feasibility of adding retention aids to the system for the purpose of retaining the clays, fillers, etc., on the felt mat. These studies, although not conclusive, indicated that up to 50 percent of the fine suspended solids could be retained which also resulted in a higher white water quality for reuse. An additional advantage is that more water could be extracted from the felt mat while it is on the paper machine, thereby increasing the efficiency and/or capacity of the dryers. Another possible method of disposing of the fines is to pump them from the bottom of the filtered water storage tank through atomized spray nozzles onto the felt mat. This was not explored and, therefore, the effects on product quality and the mechanical problems involved would have to be explored.

ECONOMIC ANALYSIS OF WATER REUSE

One of the specific objectives of this study was to conduct a cost-effectiveness analysis of alternative combinations of water reuse and by-product recovery versus waste treatment. Since the cost of fiber from waste paper is very inexpensive, the savings due to fiber recovery does not significantly affect the potential for water reuse. The fibers do, however, exert an oxygen demand and therefore affect the cost of waste treatment if they are not removed from the waste stream.

The economic feasibility of water reuse in a paper reprocessing plant is a function of the change in maintenance costs as a result of reuse. To determine the change in maintenance costs, the maintenance records before and after were compared and plant maintenance personnel were interviewed. This comparison was made by concentrating on the life of the Jordan plug and shell, the face wire on the paper forming cylinder, the pickup felt, pumps, and pipes in the system. These components were selected because they are subjected to high velocities and velocity gradients and, therefore, were expected to undergo the highest corrosion rates.

The life of the Jordan plug and shell has averaged 3½ months over a four year period prior to water reuse and there has been no noticeable change during the periods of 85 percent reuse.

Based on studies to date, which are admittedly of short duration, there has been no decrease in the life of the face wire on the paper forming cylinder as a result of water reuse. No dramatic changes have been noted in the life of the pumps and pipes in the system. A nominal number of pipes has been replaced since water reuse was initiated but none of these has failed since replacement. The assistant felt mill superintendent, who has been with the company for several years, has noticed a slight increase in the pipe failures during water reuse. He indicated this increase was 10-15 percent.

Overall, it is difficult to weigh the increase in maintenance costs incurred as a direct result of water reuse over a period of short duration unless drastic changes occur. Based on limited data, it is possible to state that there is no significant increase in maintenance of the equipment due to water reuse.

The itemized daily operational costs of the various alternatives are given in Table 8, and the yearly operational costs based on operating the plant 320 days a year are given in Table 9. The operational costs are essentially the same for all alternatives.

The capital costs of a waste treatment system required to meet the 1977 standards as set forth in PL 92-500, assuming no water reuse, is approximately $150,000. This system would not meet the 1985 standards. The capital costs of the waste treatment system required for 85 percent water reuse is $80,000 and the cost of the 100 percent water reuse system is $45,000. This is a complete retention system and, therefore, would meet the 1985 standards. The capital costs of a zero water reuse system required to meet the 1985 standards was not estimated because: 1) the operational cost of the zero water reuse alternative was slightly higher than the 85 percent water reuse system and 2) the capital cost of the zero water reuse system required to meet the 1977 standards was significantly higher than for 85 percent water reuse. The capital cost of the 100 percent water reuse system, including an additional 114 M^3 (30,000 gallon) fil-

TABLE 8. DAILY OPERATIONAL COST COMPARISON

Parameter	No Water Reuse	85% Water Reuse	100% Water Reuse
Felt	$ 12	$ 14	$ 17
Water	33	21	18
pH control	0	23	36
Slime control[a]	8	8	8
Foam control	20	20	20
Power (waste treatment)	34	14	0
TOTAL	$107	$100	$ 99

[a]Assuming quaternary ammonium compound is used, if RX-12 is used the cost would exceed $18.

TABLE 9. COST COMPARISON

Parameter	No Water Reuse	85% Water Reuse	100% Water Reuse
Operations, annual (320 days)	$ 34,240	$ 32,000	$ 31,680
Capital	150,000	80,000	45,000
Capitalized Cost	639,100	537,100	497,600

tered water storage tank which is required to insure 100 percent water reuse, is $45,000. The capital costs of the various alternatives are given in Table 9. This table also includes the capitalized cost. The capitalized cost is the sum of the construction cost plus operating and maintenance costs (O & M) capitalized by converting O&M to a sum of money at 7 percent interest which would yield the operating and maintenance costs. This does not include a sum for replacement.

The costs, of necessity, are subject to some small errors. The basic goal of this project is to meet the regulatory requirements and to do so by the least cost alternative. A benefit/cost, or cost effectiveness analysis requires an assessment of benefits as well as costs. There has been no attempt to appraise the benefits of pollution abatement, instead it is used as a constraint in assessing the costs of the three alternatives.

From Tables 8 and 9, it can be seen that though major savings in capital costs are possible, the capital costs are a relatively small amount of the capitalized costs.

If a plant had attempted to treat its wastes first, and then was forced to reuse, the cost of the 85 percent alternative would be slightly less than the 100 percent reuse alternative, that is assuming waste disposal lagoons are already in existence. It is interesting to note that the operational cost for pH control increases from 0 to $36, and the power decreased from $34 to 0 with reuse; or a trade-off between chemicals and power.

Since the operational costs are approximately the same for all alternatives, the most feasible system is one with the lowest first cost that can meet the 1985 standards. In this case, that is 100 percent water reuse or zero discharge.

SECTION VIII

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SECTION IX

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APPENDIX A-1. TEST RESULTS ON INDIVIDUAL SAMPLES OF ROOFING FELT PAPER

(NO WATER REUSE)

Sample No.	Tensile strength (g/cm)		Elongation (%)		Tear, Elmendorf (g)		Porosity, Gurley (sec/100cc)	Basis weight (g/M^2)	Caliper (mil)	Mullen (pt)
	MD	CMD	MD	CMD	MD	CMD				
1	6411	4625	7.0	6.8	264	312	5.5	516	70.0	36.0
2	7625	4625	7.0	6.8	320	328	4.4	474	65.0	40.0
3	7982	4214	6.2	7.0	328	360	4.0	529	71.0	44.0
4	6661	4000	6.8	7.0	352	528	5.3	499	70.0	38.5
5	7965	3875	6.8	7.0	304	352	4.6	508	68.5	41.0
6	7197	3571	6.2	6.8	344	424	5.7	495	67.5	44.0
7	7661	4446	6.2	7.2	296	368	5.3	495	67.0	38.5
8	7482	4107	6.2	7.0	320	376	5.7	478	67.0	40.5
9	9018	4447	6.6	7.6	304	393	5.1	504	68.5	38.0
10	7197	4929	6.2	6.8	304	320	5.3	491	66.5	37.5
11	6304	3393	6.2	7.2	304	416	5.3	516	74.5	35.0
12	7322	3661	6.6	7.2	304	383	4.1	487	70.5	35.5
13	6589	3714	6.4	8.2	296	320	4.1	478	71.0	35.0
14	7804	4322	6.4	8.2	328	384	4.2	478	65.0	35.0
15	7625	4322	6.4	7.8	368	368	4.3	495	68.0	37.5
16	8179	4322	6.6	8.8	320	392	4.2	491	68.0	37.0
17	8715	4268	6.4	8.2	352	368	4.1	461	65.0	40.5
18	6893	3929	6.4	8.4	296	392	4.0	499	71.0	35.5
19	8411	4536	6.6	7.8	304	384	4.0	483	68.0	41.0
20	7107	4286	6.4	7.6	376	352	4.3	499	67.0	34.5

APPENDIX A-2. TEST RESULTS ON INDIVIDUAL SAMPLES OF ROOFING FELT PAPER (85% WATER REUSE)

Sample No.	Tensile strength (g/cm)		Elongation (%)		Tear, Elmendorf (g)		Porosity, Gurley (sec/100cc)	Basis weight (g/M^2)	Caliper (mil)	Mullen (pt)
	MD	CMD	MD	CMD	MD	CMD				
21	7232	4143	6.4	7.4	272	288	4.0	504	68.5	36.5
22	6661	4625	6.4	7.6	256	384	4.4	512	68.5	39.0
23	6875	3786	6.6	7.6	280	328	5.6	516	69.5	36.5
24	7322	4232	6.4	8.4	264	312	5.3	487	67.0	38.5
25	7286	4179	6.6	7.0	328	352	4.9	546	72.0	45.0
26	7679	4143	6.6	8.0	320	352	4.6	508	70.0	37.0
27	7661	4232	6.4	7.4	368	385	5.0	499	68.5	39.5
28	8411	4322	6.6	7.0	288	400	4.6	495	67.0	37.5
29	6893	4053	6.6	7.4	288	416	4.1	512	68.0	38.0
30	7179	4410	6.6	7.2	328	408	5.3	497	66.0	34.5
31	8179	4322	6.8	8.0	320	448	4.7	516	71.5	38.5
32	7857	3839	6.4	6.6	304	392	5.0	499	68.5	38.0
33	8250	3929	6.2	7.2	312	368	4.6	508	70.5	39.5
34	7411	4625	6.6	8.0	320	408	4.8	483	65.5	33.5
35	7054	4286	6.6	7.6	288	344	5.1	461	63.5	35.5
36	6107	4697	6.4	7.6	296	320	4.3	521	71.0	38.0
37	7090	4467	6.6	7.8	296	304	4.0	495	68.5	41.5
38	6393	4714	6.6	7.6	376	304	4.4	521	70.5	38.0
39	7018	4322	6.4	7.2	336	352	4.2	508	69.0	39.0
40	5928	4268	6.4	7.8	272	328	4.7	508	68.5	38.5

APPENDIX B-1. WASTEWATER CHARACTERISTICS
(NC WATER REUSE)

Parameter	Machine Chest		Cylinder Vat		Cylinder Water	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
COD, mg/l O_2	1811	392	1544	250	1778	317
Chloride, mg/l	50	20	54	--	51	13
TDS, mg/l	403	172	412	110	418	105
Filterable fixed solids, mg/l	459	172	337	193	349	170
Filterable volatile solids, mg/l	1584	257	1342	232	1215	319
Nonfilterable fixed solids, mg/l	--	--	--	--	152	21
Nonfilterable volatile solids, mg/l	--	--	--	--	265	36
Alkalinity, mg/l $CaCO_3$	271	--	286	--	255	97

APPENDIX B-2. WASTEWATER CHARACTERISTICS

(NO WATER REUSE)

Parameter	Filtered Water		Hydrasieve Influent		Hydrasieve Effluent	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
COD, mg/l O_2	1269	--	1351	213	1485	350
Chloride, mg/l	55	--	60	22	46	12
TDS, mg/l	360	--	376	73	372	74
Filterable fixed solids, mg/l	350	--	268	153	323	133
Filterable volatile solids, mg/l	760	--	1075	331	1045	362
Nonfilterable fixed solids, mg/l	153	--	239	76	208	76
Nonfilterable volatile solids, mg/l	268	--	242	21	188	26
Alkalinity, mg/l $CaCO_3$	268	--	296	63	243	97

APPENDIX C-1. WASTEWATER CHARACTERISTICS

(85 PERCENT WATER REUSE)

Parameter	Machine Chest		Cylinder Vat		Cylinder Water	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
COD, mg/l O_2	--	--	--	--	5730	592
Chloride, mg/l	--	--	--	--	92	6
TDS, mg/l	1350	76	1310	95	1317	147
Filterable fixed solids, mg/l	1296	179	1151	146	1189	189
Filterable volatile solids, mg/l	4302	502	4225	385	4100	349
Nonfilterable fixed solids, mg/l	--	--	--	--	226	87
Nonfilterable volatile solids, mg/l	--	--	--	--	348	73
Alkalinity, mg/l $CaCO_3$	570	60	580	62	575	61

APPENDIX C-2. WASTEWATER CHARACTERISTICS
(85 PERCENT WATER REUSE)

Parameter	Hydrasieve influent		Hydrasieve effluent		Zurn effluent		Zurn reject	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
COD, mg/l O_2	5600	453	5469	571	5590	407	5369	224
Chloride, mg/l	90	11	90	6	91	15	91	10
TDS, mg/l	1306	108	1306	118	1243	137	1310	108
Filterable fixed solids, mg/l	1092	134	1074	143	1075	93	1122	121
Filterable volatile solids, mg/l	3825	409	3937	407	3887	256	3719	295
Nonfilterable fixed solids, mg/l	202	43	146	30	134	25	253	20
Nonfilterable volatile solids, mg/l	426	71	359	72	315	76	963	80
Alkalinity, mg/l $CaCO_3$	565	71	574	67	572	83	621	42

APPENDIX D-1. WASTEWATER CHARACTERISTICS

(100 PERCENT WATER REUSE)

Parameter	Paper Chest		Machine Chest		Cylinder Vat	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
COD, mg/l O_2	9104	2437	9160	2360	8640	2202
Chloride, mg/l	193	63	193	58	183	47
TDS, mg/l	1983	561	2066	583	1950	556
Filterable fixed solids, mg/l	2034	602	2137	740	1919	561
Filterable volatile solids, mg/l	6511	1085	6594	1386	6241	1538
Nonfilterable fixed solids, mg/l	--	--	--	--	--	--
Nonfilterable volatile solids, mg/l	--	--	--	--	--	--
Alkalinity, mg/l $CaCO_3$	1086	244	1099	251	1071	245

APPENDIX D-2. WASTEWATER CHARACTERISTICS
(100 PERCENT WATER REUSE)

Parameter	Cylinder Water		Hydrasieve Influent		Hydrasieve Effluent	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
COD, mg/l O_2	8700	2150	8726	2137	8685	2174
Chloride, mg/l	184	52	180	52	183	48
TDS, mg/l	1950	606	1917	603	1967	633
Filterable fixed solids, mg/l	1814	484	1938	592	2006	623
Filterable volatile solids, mg/l	6502	1670	6123	1679	5978	1556
Nonfilterable fixed solids, mg/l	386	82	416	73	385	55
Nonfilterable volatile solids, mg/l	874	214	849	126	811	205
Alkalinity, mg/l $CaCO_3$	1069	257	1079	253	1073	245

APPENDIX D-3. WASTEWATER CHARACTERISTICS

(100 PERCENT WATER REUSE)

Parameter	Zurn Effluent		Zurn Reject		Filtered Water	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
COD, mg/l O_2	8710	2101	8599	2216	8709	2322
Chloride, mg/l	179	43	178	47	177	45
TDS, mg/l	2000	589	1917	633	1900	638
Filterable fixed solids, mg/l	1867	542	2002	670	1929	668
Filterable volatile solids, mg/l	6202	1982	5994	1737	6109	1593
Nonfilterable fixed solids, mg/l	350	75	388	56	298	76
Nonfilterable volatile solids, mg/l	698	229	1140	223	609	285
Alkalinity, mg/l $CaCO_3$	1090	252	1083	261	1080	254

APPENDIX E-1. CORROSION RATES

NO WATER REUSE
($mg/M^2/day$)

Coupon material	Number	Rate
Brass	B-1	1.87
Stainless steel	S-1	0.02
Mild steel	M-3	37.70
	M-4	27.80
Cast iron	C-1	29.60
	C-2	30.70

APPENDIX E-2. CORROSION RATES, 85% WATER REUSE
($mg/M^2/day$)

Coupon material	Number	Rate
Brass	B-21	8.29
	B-22	1.53
	B-23	5.00
	B-24	5.30
	B-25	5.39
Stainless steel	S-20	0.05
	S-21	0.08
	S-22	0.05
	S-23	0.00
	S-24	0.00
Mild steel	M-2	38.02
	M-3	41.45
	M-4	30.51
	M-5	27.43
	M-20	50.05
	M-22	116.50
	M-23	99.50
	M-24	100.89
	M-25	65.11
	M-26	103.31
	M-27	135.69
	M-28	84.84
Cast iron	C-3	38.53
	C-4	35.01
	C-5	35.74
	C-6	35.86
	C-22	82.05
	C-26	58.34
	C-27	43.00
	C-28	75.20
	C-29	46.16
	C-30	53.19
	C-32	52.19
	C-33	56.11

APPENDIX E-3. CORROSION RATE, 100% WATER REUSE
($mg/M^2/day$)

Coupon material	Number	Rate	Number	Rate
Brass	B-1	27.60	B-6	17.77
	B-2	27.17	B-7	21.53
	B-3	26.66	B-8	22.64
	B-4	21.70	B-10	18.97
	B-5	16.87	B-26	12.70
Stainless steel	S-1	0.00	S-6	0.09
	S-2	0.00	S-7	0.09
	S-3	0.08	S-8	0.13
	S-4	0.08	S-10	0.13
	S-5	0.09		
Mild steel	M-1	115.47	M-10	74.08
	M-2	99.67	M-11	81.72
	M-3	115.22	M-12	68.01
	M-4	99.20	M-14	68.61
	M-5	75.66	M-15	72.92
	M-8	79.50	M-25	89.75
	M-9	77.41		
Cast iron	C-1	87.58	C-10	66.56
	C-2	81.08	C-11	48.10
	C-3	105.73	C-12	75.19
	C-4	88.86	C-13	56.92
	C-5	96.80	C-14	66.94
	C-7	58.23	C-15	52.67
	C-9	65.02		